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Journal

of

THE ROYAL AERONAUTICAL SOCIETY

JANUARY 1956

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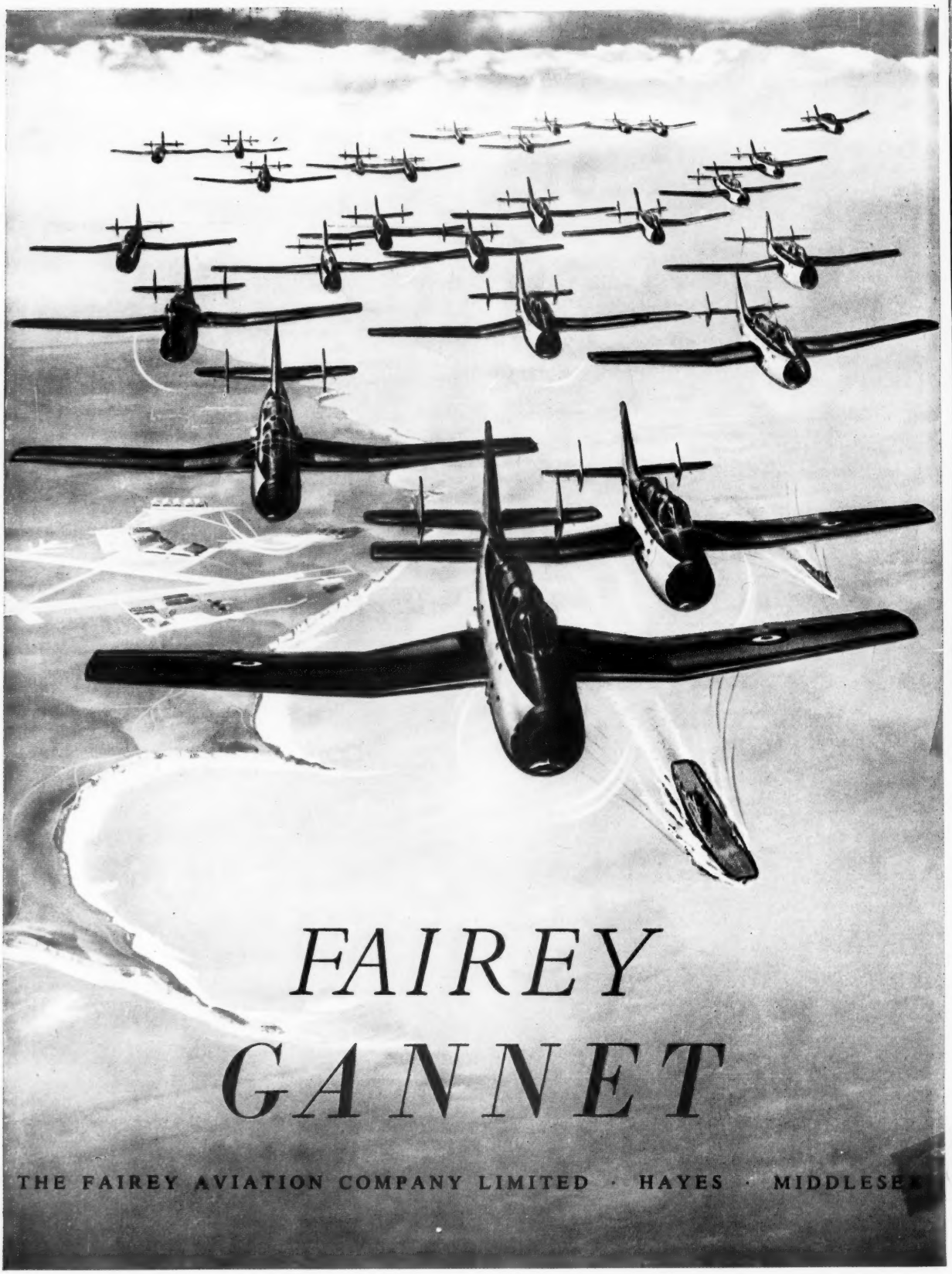
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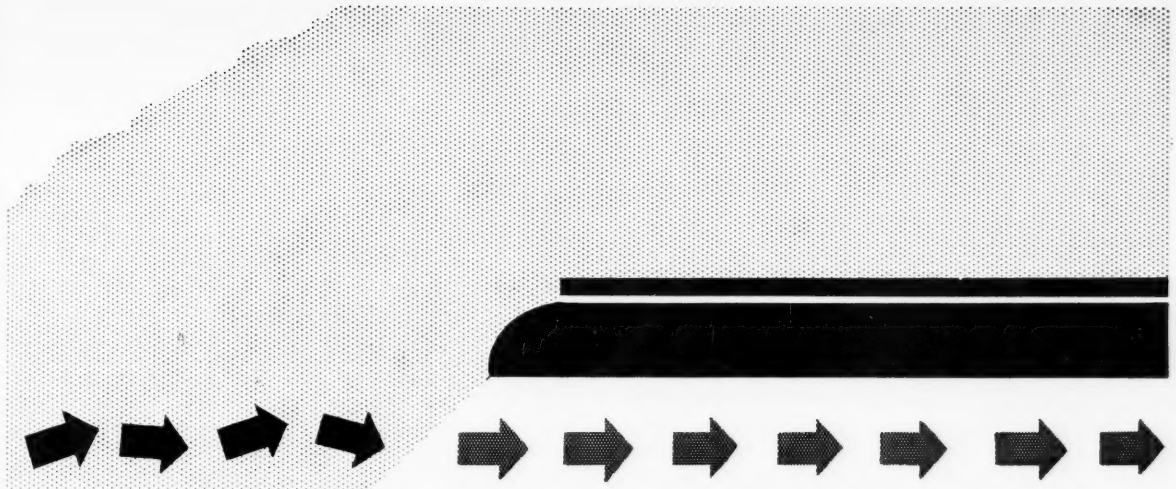

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VOLUME VII 1956

FEBRUARY MAY AUGUST NOVEMBER

Volume VII will include a series of papers on "The Jet Flap," which follow on from the introductory paper published in the January JOURNAL.

Other papers to be published in Volume VII include:—

N. J. Hoff—Creep Buckling.

P. S. Rao—Supersonic Bangs.

R. E. Meyer—Perturbations of Supersonic Nozzle Flows.

A. I. Martin—Some Integrals of the Modes of Vibration of the Ordinary Cantilever Beam and a Second Order Approximation for the Effect of a Double Taper on Overtone Frequencies.

Hugh L. Cox and *Bertram Klein*—Vibration of Isosceles Triangular Plates having the Base Clamped and Other Edges Simply-Supported.

L. Winograd and *J. W. Miles*—Numerical Results for the Longitudinal Stability Derivatives and Stability Loci of a Low Aspect Ratio Rectangular Wing in Supersonic Flow.

R. E. D. Bishop—The Mathematical Theory of Hysteretic Damping. The Behaviour of Damped Linear Systems in Steady Oscillation.

D. Williams—The Theory and Prevention of Aeroplane Nose-wheel Shimmy.

R. B. Tamboli—An Energy Approach to Climb Performance of a Jet Transport Aircraft.

A. D. Young—Note on a Theorem of Linearised Supersonic Theory Relating to the Wave Drag of Constant Section Wings with Streamwise Tips at Zero Lift.

W. S. Hemp—Fundamental Principles and Theorems of Thermo-elasticity.

S. A. Patel—Buckling of Columns in the Presence of Creep.

A. J. A. Morgan—On a Class of Laminar Viscous Flows within One or Two Bounding Cones.

J. F. Norbury—An Approximate Method for the Calculation of Turbulent Boundary Layers in Diffusers.

W. R. Hawthorne and *W. D. Armstrong*—Shear Flow through a Cascade.

R. K. Kaul and *V. Cadambe*—Vibration of Isotropic Thin Oblique Plates.

A. W. Babister—General Theorems Relating to the Stability and Response of Systems Satisfying a Second-Order Linear Differential Equation with Time-dependent Coefficients.

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Aerodynamics Data Sheets

An issue of new and revised data sheets has recently been sent to all holders of complete sets. This issue continues the policy of revising earlier data sheets as further data becomes available and revisions of several of the old sheets to cover a wider range of the parameters involved, to a greater degree of accuracy, have been prepared. New sheets have been added dealing with the following subjects: —

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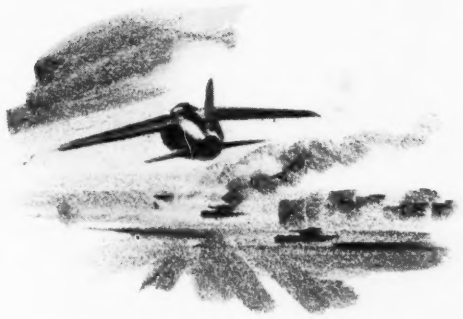

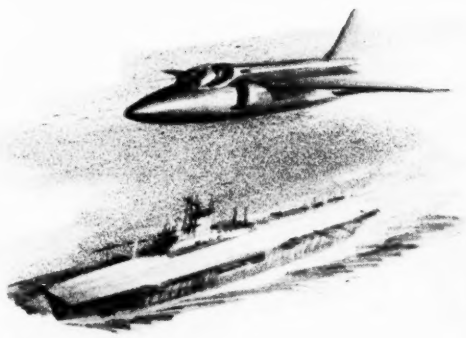

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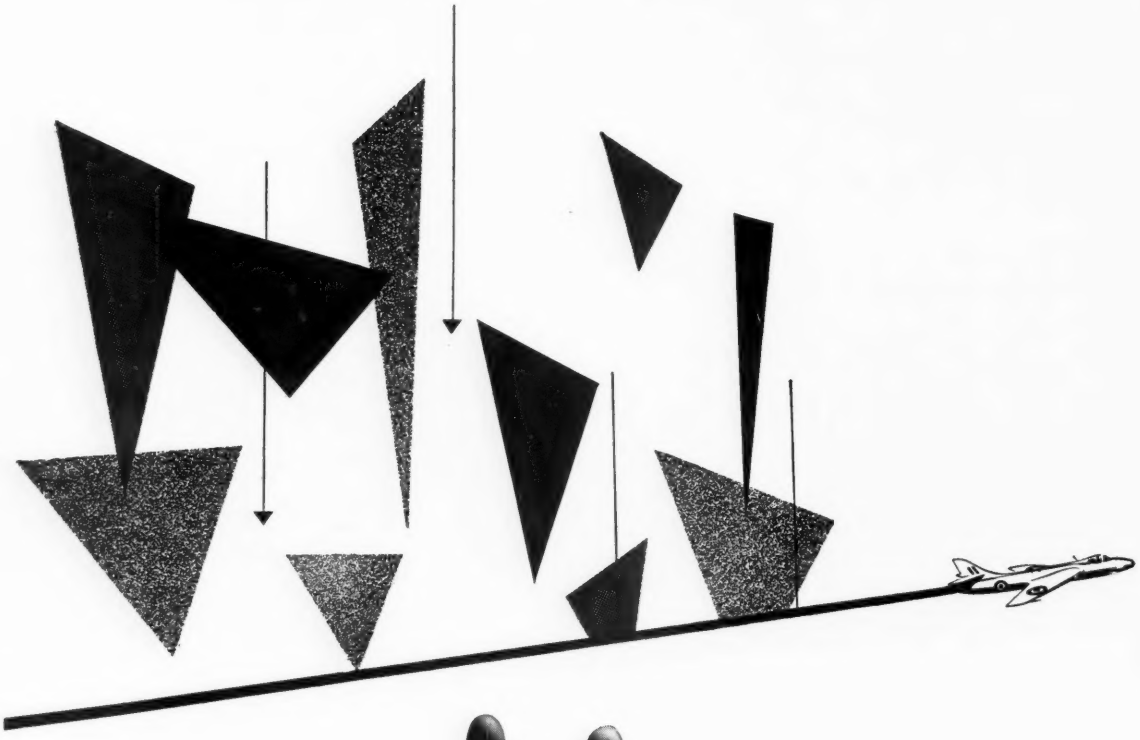

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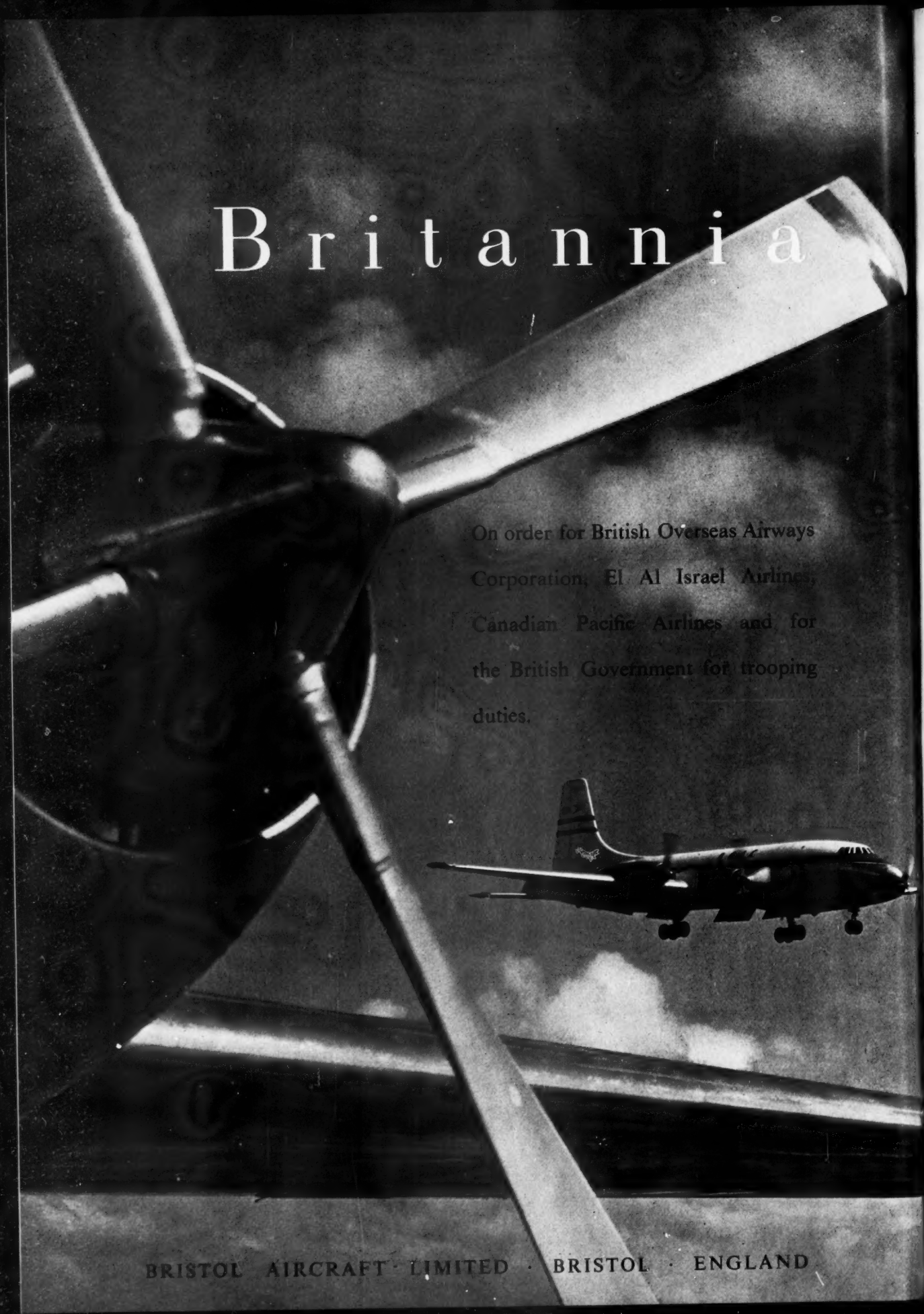
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None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

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The Journal of the Royal Aeronautical Society

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

VOLUME 60 JANUARY 1956 NUMBER 541

From the President

This Society celebrates its 90th birthday on 12th January, 1956. The progress from a small group of enthusiasts to a Chartered Professional body in that time is truly astonishing. We have already achieved a great tradition; many famous names have been, and are, numbered in our membership; aeronautics continues to deepen and grow and to expand its field of interest at an even greater pace than before. Our Society must also grow and continue to represent aeronautical art, science and engineering in this further progress as it has done so well in the past. This year will be the first of a decade, which will conclude with our Centenary Celebration, I hope in a home of our own, having reached or surpassed the aims I have attempted to set out in the Address published in this JOURNAL. We rely on the efforts and the support of all of you; may 1956 bring you happiness and a good start.

H. E. Rowe.

NOTICES

An annual sum of £250 is available for premium awards for papers, including Technical Notes, published in the Journal. Members and non-members of the Society are invited to submit papers on any aspect of aeronautics

Nominations for Fellowship of the Society

The attention of Members is drawn to the following extract from the Society's By-Laws:—

" Fellows shall comprise every person who on the 30th day of January 1950 was on the Register as a Fellow of the Society; and every person thereafter awarded the honour of Fellowship.

" Elections to Fellowship will be made annually by the Council and will be announced at the Annual General Meeting of the Society. Nominations will be initiated by the members of the Council or by any four Fellows of the Society. It is the duty of the Council to see that the honour is awarded only to persons who have attained a considerable degree of technical eminence in the profession of aeronautics."

From this, it will be seen that any four Fellows may nominate a suitable candidate for Fellowship. Nominations for 1956 must be received by the Secretary before 31st January 1956.

Associate Fellowship Examinations, June 1956

Entries for the next Associate Fellowship Examination should be received from Candidates in the British Isles by 28th February 1956. The closing date for entries outside the United Kingdom was 31st December.

Graduates' and Students' Section—Visit

An all-day visit has been arranged to the de Havilland Engine Company's works at Leavesden, for Wednesday 22nd February 1956. A weekday has been chosen in preference to Saturday, so that the machines can be seen performing their intricate operations.

Applications should be made as soon as possible to the Hon. Visits Secretary, N. K. Benson, 14 Wakering Road, Barking, Essex.

Annual Subscriptions

Members are reminded that their annual subscriptions become due on 1st January 1956. The rates are:—

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Students (aged 21 and over)	1 11 6	1 11 6
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* Any Associate elected before 1st October 1947 may, if he wishes, elect not to receive the Journal, and in this case his subscription will be reduced by £1 1s. 0d. to £2 2s. 0d.

It will avoid delay and confusion if members, when sending remittances for subscriptions, will state their names clearly and give their addresses and grades of membership. Remittances should be made payable to the Royal Aeronautical Society.

News of Members

T. Bancroft (*Associate Fellow*) for many years General Works Manager has joined the Board of Blackburn & General Aircraft Limited.

A. C. Brown (*Fellow* and formerly a *Member of Council*) has retired from his post as Chief Techn. (Res.) with the Fairey Aviation Company.

A. B. M. Brush (*Associate Fellow*) has joined the Lockheed Aircraft Corporation at Burbank, California.

H. Cantrill (*Fellow*) has retired from Rolls-Royce Limited where he held the post of Chief Quality Engineer, Aircraft Engines.

E. N. Crabbe (*Associate Fellow*) has recently taken up an appointment as Flight Test Engineer with Folland Aircraft Limited.

J. E. P. Dunning (*Associate Fellow*) has been appointed Chief Superintendent of the Rocket Propulsion Department, Royal Aircraft Establishment.

J. F. Foss (*Associate Fellow*) has joined Scottish Aviation Limited, Prestwick, as Project Aerodynamicist.

E. Garner (*Associate*) has joined the Directorate of Civil Aviation in charge of Air Traffic Control at Nairobi.

I. A. B. Gaunt (*Associate Fellow*), formerly with the Plessey Company, is now with the Atomic Energy Department of the General Electric Company.

A. J. Goodwin (*Graduate*) has joined Rolls-Royce Limited at Crewe as Development Engineer.

L. S. Greenland (*Associate Fellow*), Chief Designer of H. M. Hobson Limited, has been appointed to the Board of Directors.

W. A. Hargreaves (*Fellow*) has retired from full time duties with Blackburn & General Aircraft Limited but will remain on the Board.

Wing Commander R. V. Moxey (*Associate*) has taken up an appointment in the Directorate of Aircraft Engineering, Air Ministry.

M. E. L. Spanyol (*Graduate*), formerly Aerodynamicist at the Gloster Aircraft Company, has been appointed Operations Development Officer with B.O.A.C. at London Airport.

H. J. B. Thompson (*Associate*) has joined Rolls-Royce (Scottish Factories) as a Technical Assistant in their Overseas Overhaul Department.

A. C. Campbell Orde (*Fellow*) and E. W. C. Wilkins (*Fellow*) were recently elected Associate Fellows of the Institute of the Aeronautical Sciences.

The Wright Brothers' Memorial Trophy for 1955 has been awarded to Dr. H. L. Dryden (*Fellow*). The award has been made annually since 1948 for " significant public service of enduring value to aviation in the United States."

Gas Turbine Technology

A course of ten lectures on " An Introduction to Gas Turbine Technology " by R. C. Orfold, M.Sc., C.P.A., A.M.I.E.E., Patent Manager of Power Jets (Research and Development) Ltd., will begin on 17th January at the Northampton Polytechnic, St. John Street, London, E.C.1.

DIARY

LONDON

10th January

SECTION LECTURE.—Some Modern Structural Problems. Prof. W. S. Hemp. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

12th January

PRESIDENTIAL ADDRESS.—N. E. Rowe, C.B.E. The Royal Institution, 21 Albemarle Street, London, W.1. **6 p.m.** (Tea 5.30 p.m.)

RECEPTION.—7.30 - 10.00 p.m. 21 Albemarle Street. London, W.1. (Tickets, which include Buffet Supper, from 4 Hamilton Place.)

17th January

SECTION LECTURE.—Crack Detection in Aircraft Structures. Dr. W. Deck. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

24th January

SECTION LECTURE.—Low Consumption Jet Engines. A. A. Lombard. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

2nd February

SECTION LECTURE.—New Ideas in Plastics for Aircraft Structures. J. E. Gordon. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

9th February

SECTION LECTURE.—Propellers for Military and Civil Aircraft. L. G. Fairhurst. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

16th February

Main Lecture at Yeovil Branch.—THE FIRST HENSON AND STRINGFELLOW MEMORIAL LECTURE. Dr. A. M. Ballantyne and Captain J. L. Pritchard. 7.30 p.m.

21st February

SECTION LECTURE.—Design of Low Landing Speed Aircraft. R. C. McIntyre. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

28th February

SECTION LECTURE.—Use of Elementary Plasticity in Design. Anthony J. Barrett. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

1st March

SECTION LECTURE.—Power Plants for Supersonic Flight. Dr. E. S. Moult. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

7th March

The Ninth Louis Bleriot Lecture—In Paris—The Organisation of Aeronautical Research. E. T. Jones, C.B., O.B.E. Details will be published later.

GRADUATES' AND STUDENTS' SECTION

18th January

Visit to Wine Cellar in Central London (*See* notice).

31st January

Laminar-Flow Aircraft Design. J. B. Edwards. The Library, 4 Hamilton Place, London, W.1. 7.30 p.m.

14th February

Flight-Testing of High-Speed Aircraft. T. H. Kerr. The Library, 4 Hamilton Place, London, W.1. 7.30 p.m.

22nd February

Visit to de Havilland Engine Co., Leavesden, Herts. (*See* notice).

6th March

Annual General Meeting and Film Show. The Library, 4 Hamilton Place, London, W.1. 7.30 p.m.

28th March

Artificial Space Satellites. A. V. Cleaver. The Library, 4 Hamilton Place, London, W.1. 7.30 p.m.

BRANCHES

10th January

Boscombe Down.—Fatigue: The Metallic Deathwatch Beetle. D. C. Smith. Lecture Hall, A. & A.E.E., Boscombe Down, Amesbury, Wilts. 5.45 p.m.

Bristol.—Aerodynamics and Associated Problems. R. F. Creasey. Conference Room, Filton House, Bristol Aeroplane Co. 6 p.m.

11th January

Brough.—Passengers and Freight Handling by Transport Command. Wing Cdr. P. J. George. Lecture Hall, Yorkshire Electricity Board, Ferensway, Hull. 7.30 p.m.

Chester.—Supersonic Flight. G. A. V. Tyson. The Grosvenor Hotel, Chester. 7.30 p.m.

Manchester.—Analogue and Digital Computors Applied to Aircraft Design. J. Arrowsmith. Reynolds Hall, College of Technology, Manchester. 7.30 p.m.

Weybridge.—Brains Trust. Vickers-Armstrongs (Aircraft) Ltd., Weybridge. 6 p.m.

12th January

Cheltenham.—Liquid Springs: Progress in Design and Application. A. E. Bingham. (Originally given before the Institution of Mechanical Engineers). St. Mary's College, Cheltenham. 7.30 p.m.

16th January

Halton.—Jaguar Cars. Film and Talk. J. Barker. Branch Hut, R.A.F., Halton. 6.45 p.m.

17th January

Bristol.—Power Plants for Supersonic Flight. Dr. E. S. Moult. Conference Room, Filton House, Bristol Aeroplane Co. 6 p.m.

18th January

Reading and District.—Progress in Gliding. A. H. Yates. Canteen, Western Manufacturing Ltd., Reading. 6 p.m.

20th January

Birmingham.—President's Night. Birmingham Engineering Centre, Stephenson Place, Birmingham. 7.30 p.m.

Leicester.—Annual General Meeting and Film Show. Lecture Theatre, Loughborough College.

23rd January

Halton.—Underwater T.V. C. C. MacNeice. Branch Hut, R.A.F., Halton. 6.45 p.m.

24th January

Belfast.—The Turbulent Atmosphere. Eric Hyde. Kerr Room, Kensington Hotel, Belfast. 7 p.m.

Bristol.—Aeroelastic Problems in Connection with High-Speed Flight. E. G. Broadbent. Conference Room, Filton House, Bristol Aeroplane Co. 6 p.m.

26th January

Isle of Wight.—Interplanetary Flight. A. V. Cleaver. Clubhouse, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6.30 p.m.

Yeovil.—Patents Brains Trust. Park School, Park Road (off Princes Street), Yeovil. 7.30 p.m.

30th January

Halton.—Film: The Wooden Horse. Branch Hut, R.A.F., Halton. 6.45 p.m.

Henlow.—Lecture. W. H. Lindsey. Building No. 62, R.A.F. Technical College, Henlow. 7.30 p.m.

31st January

Belfast.—Pressing, Stretching and Bumping. L. Fromson. Reception Room, Kensington Hotel, Belfast. 7 p.m.

1st February

Gloucester.—Aircraft Fatigue. H. Giddings. The Wheatstone Hall, Brunswick Road, Gloucester. 7.30 p.m.

Preston.—Debate. R.A.F. Association, Preston. 7.30 p.m.

Weybridge.—R. K. Pierson Memorial Lecture. Vickers-Armstrongs (Aircraft) Ltd., Weybridge. 6 p.m.

2nd February

Brough.—Some Meteorological Problems of High Altitude Flight. P. J. Meade, O.B.E. Lecture Hall, Yorkshire Electricity Board, Ferensway, Hull. 7.30 p.m.

6th February

Derby.—Propeller Turbine Engines for Naval Aircraft. W. H. Lindsey. Rolls-Royce Welfare Hall, Nightingale Road, Derby. 6.15 p.m.

Halton.—Developments of Ram-Jets. Sqn. Ldr. R. C. Rogers. Branch Hut, R.A.F., Halton. 6.45 p.m.

7th February

Boscombe Down.—The Future of Air Power. Air Marshal Sir Robert Saundby, K.B.E., C.B., D.F.C., A.F.C. Lecture Hall, A. & A.E.E., Boscombe Down. 5.45 p.m.

8th February

Chester.—Future Car Developments. The Grosvenor Hotel, Chester. 7.30 p.m.

Manchester.—The Artificial Stabilisation of Modern Aircraft. Dr. K. H. Doetsch. Reynolds Hall, College of Technology, Manchester. 7.30 p.m.

10th February

Brough.—Annual Dinner Dance. Jacksons Ltd., Hull.

Glasgow.—FIRST PILCHER MEMORIAL LECTURE. I. R. Liddell. Royal Technical College, Glasgow. 7.15 p.m.

13th February

Halton.—Film: Journey Together. Branch Hut, R.A.F. Halton. 6.45 p.m.

Henlow.—Annual General Meeting. Building No. 62, R.A.F. Technical College, Henlow. 7.30 p.m.

14th February

Bristol.—Aerial Photography. Charles E. Brown. Conference Room, Filton House, Bristol Aeroplane Co. 6 p.m.

15th February

Coventry.—Lecture. E. P. Hawthorn. The Wine Lodge, Coventry. 7.30 p.m.

Halton.—Visit to Smith's Aircraft Instruments Ltd., Bishop's Cleeve, Cheltenham.

Reading and District.—Lecture and Film Show. Guided Weapons. Sqn. Ldr. R. E. W. Harland. Western Manufacturing Ltd. Canteen, Reading. 6 p.m.

16th February

Isle of Wight.—Operations of Turbo-Propeller Aircraft. P. G. Masefield. Clubhouse, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6.30 p.m.

Yeovil.—MAIN LECTURE: First Henson and Stringfellow Memorial Lecture. Dr. A. M. Ballantyne and Captain J. L. Pritchard. 7.30 p.m.

17th February

Birmingham.—Some Aspects of Metal Fatigue. Prof. S. J. Murphy. The Birmingham Engineering Centre, Stephenson Place, Birmingham. 7.30 p.m.

21st February

Belfast.—The New London Airport. R. F. Bulstrode. Kerr Room, Kensington Hotel, Belfast. 7 p.m.

22nd February

Weybridge.—Training and Research in the Field of Aircraft Production. Professor J. V. Connolly, B.E. Vickers-Armstrongs (Aircraft) Ltd., Weybridge. 6 p.m.

23rd February

Cheltenham.—The Investigation of Flutter by Flight Tests. H. G. Peacock. St. Mary's College, Cheltenham. 7.30 p.m.

24th February

Leicester.—Lecture. Lecture Theatre, Loughborough College.

ELECTIONS

The following is a list of new members and transfers of membership:—

Associate Fellows

Denzil Arthur Ashover (*from Student*)
Eric Brelsford (*from Graduate*)
David John Cockrell (*from Graduate*)
Bertram Cornthwaite (*from Associate*)
William Allan Crawford
Bernard Francis Dawton
William Ernest Digweed (*from Graduate*)
Wilfred James Eggington (*from Graduate*)
Ambrose Wright Eyre
Edwin Frederick Faggetter (*from Associate*)
Robert Black Farmer
Robin Beadon Lisle Foster (*from Graduate*)
Harold Beaton Grant (*from Graduate*)
Ronald Basil Griffiths (*from Associate*)
Victor Ransford Haas (*from Student*)
Norman Wilfred Jones (*from Associate*)
Sydney Kelsey (*from Graduate*)
David Gwynne Maitland
Rodney Edwin Matlock
Douglas Mercer
Philip John Mitchelmore (*from Graduate*)
Stephen Pallis
Hugh Marcus Geoffrey Parker
John Rose
Stanley Stephen Schaetzel (*from Graduate*)
Geoffrey Gordon Semark (*from Graduate*)
Anthony James Cotter Smith
Jerzy Terajewicz (*from Graduate*)
Peter Murray Twiss (*from Graduate*)
Robert Craven Walker (*from Graduate*)
Charles Duncan Henry Webb
James Herbert William Wheatley (*from Graduate*)

Associates

Henry Addinell
Arthur Edward Mackenzie Barton (*from Graduate*)
Alexander Dewar
Fred Harden
Andrew Derek Chisenhale Harding
Robert William Howes (*from Companion*)
Charles Leslie Josiffe
Gordon Bell McNab
Ralph Cyril Moring
George Jones Salisbury
Douglas Ferdinand Shallow
Bernard Reuben Shelton

Graduates

Keith Adams
Walter Melville Albert
James Frederick Barnes
Denys Stanley Bliss (*from Student*)
Peter Geoffrey Bricheno
Malcolm Gordon Cherry (*from Student*)
James Rattray Cownie (*from Student*)
Stanley Maurice Cobb
Joseph Jayaratnam David
Norman Robert Dobson
David John Evans
Peter James Ford
Peter Hickman
Brian Arthur Kerry
Paul Minton
Terence Pugh O'Brien
Gordon Oulsnam (*from Student*)
Albert Penny
Thomas Harford Richards
Hansgeorg Riedel (*from Student*)
Mark Macdonald Robertson
Kyriakos Christaki Valanis
Michael John Webber
John Robertson Wedderspoon
John Foster Wilby (*from Student*)

Students

Donald John Acklam
Ian Ainslie
Krishan Lal Arora
Gordon Ross Bamford
Brian Lucas Bennett
Peter Gerald Boid
Ronald Tom Bullus
Peter Burrows
John Barry Carr
Terence Coates
Dennis Victor Coulby
Andrzej Ludomir Roman Dziwinski
Anthony John Eyles
Kenneth Farrance
Clive Raymond Foster
David Norman Foster
Michael Arthur Grace
Derrick William Gray
George Stanley Hewson
Harvey Holtby
David Hyde
Kenton John Ide
Lloyd Ross Jenkinson
Robert Jennings
John Godfrey Joyce
Michael Judd
Farrokh Ardeshir Kohiyar
Michael Philip Laker
John Robert Lamb
Peter Laws
Richard Mason
David John Maull
Maurice Millard
David Patrick Moakes
Raymond Carey Morgan
Roy Granville Noble
David Norris
John Francis Anthony O'Gara
Philip Anthony Conacher Oldfield
Robert James Pate
Barry Pitchfork
Geoffrey George Pope
Frank Malcolm Rands
David John Shingler
Alan George James Smith
Sidney John Swadling
Peng Nam Tan
Robert Thomas Frederick Vanstone
Richard Watson
Arthur Lawrence Webb
Jack Gifford Wheeler
Geoffrey Whitehead

Companions

Arthur Ernest Lampard
Joseph Sacharin (*from Student*)

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The Journal of the Royal Aeronautical Society

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

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Presidential Address

An Address by the President, MR. N. E. ROWE, C.B.E., Wh.Ex., A.C.G.I., B.Sc., D.I.C., M.I.Mech.E., F.C.G.I., F.I.A.S., F.R.Ae.S., was given before the Society at the Royal Institution, 21 Albemarle Street, London, W.1, on 12th January 1956—the 90th Anniversary of the Society. The Presidential Address was followed by a Reception which was also held at the Royal Institution.

I HAVE a deep conviction that an address by the President is good for the Society—and for him. It enables the President to make a broad review, to comment on the aeronautical situation as he sees it and particularly on the state of the Society, its policy and its future. I ask for your forbearance if I say those things which are the consequences of my deep conviction, but with which you may not always agree. I hope that, in future, the Presidential Address may become a major event in our Calendar.

So far as I can trace this is the third Presidential Address presented before the Society. The previous ones were both given by great men in aeronautics, the first in January, 1903 by Major Baden-Powell, President 1900-1907, and the second in April, 1937 by Mr. H. E. Wimperis, President 1936-1938. Major Baden-Powell, just home from the South African War, reviewed the then state of aeronautics; he was well qualified to do so having been elected a member of the Society in 1880 and served as its Honorary Secretary since November, 1896. He founded the *Journal*, offering to publish it at his own expense and risk; in fact the Council, when he went abroad in 1899, recorded that as Honorary Secretary he had virtually re-established the Society. His membership continued for 57 years; this Society and aeronautics owe him a great debt.

Mr. Wimperis spoke on "The Natural Limits to Human Flight" and his Address is well worth reading today. He was the first Director of Scientific Research in the Air Ministry and laid the foundations for the research organisations and work which has made and continues to make such a vital contribution to aeronautical advance. He, also, gave great service to this Society.

As the third in this line I feel quite unworthy; however I find great encouragement in recollecting that this is an extremely interesting and important date in the annals of our Society since it is of the Society that I wish to speak. It was on 12th January, 1866 that a number of men interested in aeronautics came together at the house of the Duke of Argyll for the purpose of founding a Society "... for the advancement of aerial navigation and for observations in aerology connected therewith." The Duke of Argyll was elected President, a post which he filled for 29 years. The Duke of Sutherland, Lord Richard Grosvenor and Lord Dufferin were elected Vice-Presidents. The Council included famous scientists and engineers of the day and a number of them continued to serve on the Council for many years. In particular, the Honorary Secretary, Mr. F. W. Brearey, who had been very active in promoting the Society, remained to do most valuable work as Honorary Secretary until his death in 1896. The first point to note, I think, is that all concerned were amateurs in the science and art of aerial navigation which we now call aeronautics. Men of great vision, many of them, and quite prepared to stand up to very solid criticism and even derision because they believed in this new science. Of course at that time there had been many balloon ascents and James Glaisher, F.R.S., of the Council made some of the greatest, but amongst those who were elected were a number who believed that the real future of aeronautics lay in heavier-than-air machines. In fact Mr. Wenham, one of the members of the Council, in the first Address given to the Society in June, 1866, gave some penetrating views and theories about the forces acting on plane surfaces in an air stream, and his paper is well worth reading even today. Prior to this time we had in this country a very great amateur of aeronautics, Sir George Cayley*, the Father of British Aeronautics, who had made attempts twice at earlier stages to get together a Society of those who were interested in this new science, this very far-off science in those days.

Baden-Powell's Address was not quite half way in time between the date of formation of the Society and the present time. It was also only 11 months prior to the first powered fully controlled flight of a heavier-than-air aircraft. Baden-Powell referred to the work of the Wright Brothers who at that time were known to have made very great progress in the art of gliding and to have obtained a mastery which was acknowledged on an international basis, but there was no hint in his Address that such a spectacular flight as the one which was made at Kittyhawk on 17th December, 1903, would be so soon.

The primary purpose of my Address on this the 90th Anniversary of the Founding of the Society, is to review our present position, to establish broad objectives for

*The First Cayley Memorial Lecture, "Sir George Cayley, Bart., The Father of British Aeronautics," *Journal of the Royal Aeronautical Society*, No. 530, Vol. 59.

the future and to state some of the recent major policy decisions which the Council, advised by the Future Policy Committee, has taken. In the process of this review I hope to trace the evolutionary change in the relation between the Society and aeronautics over the years. In particular, to trace the evolution from an essentially amateur body of enthusiasts to the present stage when we see a powerful professional Society which is fully representative of aeronautics in this country and in the Commonwealth, and one which covers an extremely wide and growing range of scientific and engineering specialisations.

At the commencement, it is of interest to note points of similarity and of contrast between our ideas now and those which were extant at the time of the first Presidential Address. In particular, there is no loss whatever of the vision and sense of pioneer activity. In fact, although our horizons have widened immeasurably in the past 52 years, the sense of having tremendous scope, so clear then, remains equally attractive to bold and adventurous minds. The basic feature of aeronautical progress at the time was an experimental approach, in gliding work, the experiments with kites, and balloon ascents mainly used for the purpose of obtaining meteorological data. One of the great desiderata of the time was an engine light enough for the power required to overcome the drag of the fixed wing and associated surfaces and structure at the speed of sustentation in flight. The major attempts had been via the steam engine by Stringfellow, Moy and Maxim and they had produced both ingenious and striking results in the process of their development. This is comparative with our own day, when there continues to be search after the lightest power plants, and no doubt this search will be a feature of conventional aeronautics as it continues to develop. In striking contrast is the general status of the Society which was a small body about 150 strong composed of amateurs of aeronautics, many having very wide professional interests of their own, but prepared to devote a great deal of their time and effort to this fascinating new subject.

The *Journal* of 1903 is of very great interest. In it is an article by Bryan, I suppose the first he published, on the fundamental question of aircraft stability. There is an account of a kite flying competition in which the objective was to reach a height of 3,000 ft. or more, and in that the President of the Society engaged and also such a famous man as S. F. Cody, who later did such striking work as a designer, constructor and pilot at the old Balloon Factory which was established at Farnborough in 1910. The same Journal contains an article by Wilbur Wright, and records work on balloons and also work of great interest in meteorology. The puzzle of bird flight was still not completely understood, but a firm conclusion had been reached that birds did not obtain their result by tremendously powerful efforts. In other words, that the power plant for flight was not out of reach but it was probably obtainable if we could find the right means of turning some form of energy into some form of thrust. In fact one may think of the Society of the day as a sounding board attracting fundamental contributions such as Bryan's, contributions from close observers of the examples of flight in nature, but very little of a strictly theoretical kind, since most of those concerned were essentially practical men who wanted to make practical experiments.

I referred earlier to the paper by Wenham. This was the first paper ever presented before the Society; it provoked a very good discussion on the general problems of heavier-than-air flight; it made an extremely penetrating attempt to explain where the forces for the support of the vehicle came from. A feature of the discussion was that it was animated, forthright, practical in the assessment of what was possible, and also scientific. There was no doubt about the enthusiasm of those who were our forebears in the early days of the Society. They had no data, little knowledge other than that acquired from their own observations, there was very little theory and their work was entirely speculative. There was no established aeronautical industry and there was nothing to reward them for their efforts except the great prospect of conquering the air. This prospect was assessed differently by different observers. A Military man such as Baden-Powell thought of it as being a revolutionary means of obtaining a Military advantage; Cayley, on the other hand, from the outset thought of the air as an ocean, in which it would be of the greatest advantage to civilisation to move freely from place to place without let or hindrance of mountains or other barriers and he had perhaps the greater vision of the best use of this new science.

The position of the Society in relation to the general public in 1903 was very little different from what it had been at its foundation in 1866; there had been some spectacular balloon ascents, there was enough interest to attract a crowd of 1,000 to go to a remote spot on the Sussex Downs for the Kite Flying Trials, but there was still no practical conviction that the conquest of the air was about to come. One senses that these practical men were feeling rather strongly in their ideas about the possibilities of flight, but everything was still very elementary. The public in the main was good humoured but really quite unconvinced and quite prepared to submit to ridicule the Balloonatics as they were called, and even more so those who thought that a piece of structure could ever be made to remain aloft of its own volition. It is interesting to attempt to form an opinion of how our Society looks to the outside observer today. Does it actively represent the vast importance of our work? Does it really act adequately for the advancement of Aeronautical Art, Science and Engineering? Does it still retain the vision of aeronautical progress which inspired it in those early days?

In 1903, when Baden-Powell gave his Presidential Address, the Society was just recovering from a slump during which there had been an almost complete loss of interest amongst scientific men, the membership was reduced to a handful and the gallant efforts of F. W. Brearey, Honorary Secretary since the founding of the Society and now an old man, were unavailing. It was only the courageous and enthusiastic resolute action of a few, including Baden-Powell, which resulted in resuscitation of interest late in 1896 and a healthy condition in 1903. Possibly it is at this stage that one

detects the first significant change in the character of our Society, attracting, via reports of great work of Maxim and Pilcher here, Lilienthal in Germany, Langley and Chanute in the United States and Hargrave in Australia, a new class of membership recruited from the Services, individual inventors, experimenters and the interested middle class public, as distinct from the patrons of science and men of great scientific achievement and reputation who had joined in the movement at the outset. We witnessed then the brilliant flame kindled by men of great vision, wide attainments and great convictions, doubtless the work of Sir George Cayley, Henson and Stringfellow and others had provided the early stimulus, but to the Duke of Argyll, the first President, James Glaisher, the Honorary Treasurer, and to F. W. Brearey, the Honorary Secretary, who continued until 1896, belongs the honour of the foundation of our Society. As we have seen, the early flame died down, but what replaced it was more the steady glow well established and ready to advance and burst into new and greater brightness as opportunity offered.

The aeroplane attracted the notice of the professional soldier; in the summary of a remarkably prescient article, 'Flight and Flying Machines—Recent Progress,' published in the July, 1897 Number of *The Aeronautical Journal*, Major J. D. Fullerton, R.E., wrote:—

"To sum up:—

1st In the near future, aerial warfare by swift flying air-ships will revolutionise the present methods of war by sea and land.

2nd Owing to the high rate of speed of the air-ships, all nations will have to maintain themselves ready for war *at very short notice.*

3rd The nations most affected by aerial warfare will be those which depend at present for their defence on marine navies.

4th As aerial ships will be, comparatively speaking, inexpensive, the smaller nations will be able to make use of them.

5th Owing to the possibility of war at very short notice, a larger proportion of a nation will have to be kept under arms.

6th Warfare by sea and land, on any extended scale, will only be possible to the nation which has command of the air."

This was written nearly 60 years ago. The writer thought little of the use of the flying machine for peace, contrasting with Sir George Cayley who wrote of

"the dry navigation of the universal ocean of the terrestrial atmosphere"

and in his great paper 'On Aerial Navigation,' published in 1809*:—

"I am induced to request your publication of this essay because I conceive in stating the fundamental principles of this art, together with a considerable number of facts and practical observations that have arisen in the course of much attention to this subject, I may be expediting the attainment of an object that will in time be found of great importance to mankind; so much so that a new era in society will commence from the moment that aerial navigation is familiarly realised."

In their visionary thought they were both right; we are in the middle of the revolution of the 'present methods of war by sea and land'; we have seen victory achieved by this air power and peace preserved by the same power. Daily we witness the passage of aircraft on their lawful occasions through the ocean of air. We have seen Tennyson's prophetic vision come alive:—

"For I dipt into the future, far as human eye could see,
Saw the vision of the world, and all the wonder that would be;
Saw the Heavens filled with commerce, argosies of magic sails,
Pilots of the purple twilight, dropping down with costly bales,
Heard the Heavens fill with shouting, and there rained a ghastly dew,
From the nations' airy navies, grappling in the central blue."

May Heaven preserve us all from ever seeing the dread reality of the 'ghastly dew.'

But at the beginning of the present century few dreamed these dreams although there were individual workers of great power in this country, in Germany, in France, and in the United States the genius of the Wright Brothers was clearing the path to the great but at the time almost unrecognised triumph of 17th December, 1903. Military interest quickened as the Wrights perfected their invention and made convincing demonstrations with their Flyers in the United States, and in Europe. Military men received training as pilots from 1906 onwards.

I suppose one can think of them as the advance guard of the great profession of Aeronautics of which we are all so proud. But for the moment they are soldiers who can fly, a new sort of cavalry capable of a swifter, bolder, more complete form of reconnaissance. Soon, however, in 1908, we have the great S. F. Cody flying his first biplane (built as a P.V.) from the field of the newly-established Balloon Factory at Farnborough, Hampshire. This same place saw the beginning of many professional careers in Aeronautics when, in August, 1914, the chariot of war harnessed to its aid this youthful, vigorous, new art of flying so long the happy field of the eager amateur—and to what end? To what have their efforts led, these pioneers in the profession of Aeronautics, what are the results—where is the 'vision splendid'? Where but in the use of air power today to preserve peace and to promote those swift movements of men and materials in the peaceful traffic of the world so much needed to foster and enlarge the arts of peace. Maybe if one steps down into the daily ruck, things are

*See Appendix to First Cayley Memorial Lecture.

noisy, rough, irregular, but there is the great and glowing picture, showing the immense roles of the science and art of aerial navigation in the ways of peace. May I remind you that a dictionary definition of 'Aeronautics' is 'the Science and Art of Aerial Navigation'—and that we are the Royal Aeronautical Society.

One of the clearest statements of the great part to be played by air power in peace was given by the Duke of Edinburgh in his Commonwealth Lecture before the Society in December, 1954 on "Aviation and the Development of Remote Areas."* To quote from his Conclusion ". . . aviation has become a vital and integral part of the civilisation of the countries of the Commonwealth and Empire and that their further development depends upon operators demanding, and the aircraft industry producing, machines capable of doing a wide variety of work cheaply and efficiently." He was, of course, referring to the outback and to those remote areas wherein communications by other than the air are difficult, uncertain and extremely slow. But there is no doubt that as aeronautics develop and communications by air are extended and improved, aviation will become, in no long time, equally a vital and integral part of civilisation in the areas where surface communications are now most developed and widely used. Thus the future of aviation for peaceful ends seems assured; we know it to be vital for military purposes. How does our Society propose to keep pace with this phenomenal growth in aeronautics and its many-sided applications?

Before answering this question may I sketch in some of the background, very little, in relation to the total activity of the Society, but enough perhaps to give the perspective and the vista of change which has brought us to this 90th Anniversary.

The list of Presidents is illuminating in many ways, because it shows such a clear trend in the character of the Society and includes so many names famous in British and indeed in world-wide aeronautics. For the sake of completeness, this tale of our Past Presidents is given as an appendix to this Address. We remember them with affection, respect and a most lively sense of gratitude. Our Founder and his period I have already mentioned, as also our spiritual founder the very great Sir George Cayley who, one thinks, most certainly would have flown had he possessed the light power plant he so clearly saw to be necessary—here indeed is the "Patron Saint" for weight engineers.

After the Duke of Argyll's long reign from 1866 to 1895 the Presidency fell into abeyance until Baden-Powell took over in 1900 to 1907. Here was the practical soldier, most energetic and competent Honorary Secretary, practical man of affairs, and here we see the first transition from noble patron to practical experimenter.

From 1912 to 1926 the business of the Council was presided over by a Chairman; we find the transition continuing and professional men of science and engineering emerging—Lieut.-Col. O'Gorman, Chairman 1921-22, Superintendent of the Royal Aircraft Factory in the very important years 1909-16, he urged the need for research in aeronautics more than any man and led the Society in pressing the Air Ministry to appoint a a Director of Scientific Research; Professor L. Bairstow (now Sir Leonard Bairstow) First Zaharoff Professor of Aeronautics in the University of London, Chairman 1922 to 1923; Lieut.-Col. H. T. Tizard (now Sir Henry Tizard) founder of the Armament and Aircraft Establishment at Martlesham Heath in 1919, Chairman of the Aeronautical Research Committee 1933-1943, a household name in defence science leadership and policy during and since the Second World War, Chairman 1924 to 1925; the great Director-General of Civil Aviation, Sir Sefton Brancker, Chairman 1925 to 1926 and President 1926 to 1927. Finally we have the first of the professional engineers C. R. Fairey (now Sir Richard Fairey), President 1930 to 1934, followed by a succession of eminent scientists and engineers from industry and Government service.

The transition from the noble patron of arts and science to the more practical man of affairs and then to the professional man of science or industry is easy to mark, a transition from the speculative through the experimental to the practical and utilitarian in the science and art of aeronautics itself. The professional succession is clear from 1930; the advance in aeronautics in 65 years had been astonishing, but our Society was keeping pace in its activities, its organisation and its leadership.

A similar transition can be traced through the lectures, published papers and other activities of the Society. Making the briefest selection: in 1867 Dr. Smyth, L.R.C.P., gave a paper entitled "Experiments Practically Demonstrating the Laws by which Birds Fly and the Application to an Aerial Machine"; in 1874 P. S. Brown spoke on "The Aero Bi-plane or First Steps to Flight"; in 1887 Mr. Douglas Archibald read a paper "Kite Balloons and Kite Tandems"; in 1893 the great Horatio Phillips of 'Phillips' Entry' fame wrote "On the Sustentation of Weight by Mechanical Flight"; in 1901, Sir Hiram P. Maxim on "Aerial Navigation by Bodies Heavier than Air"; Orville Wright in 1905 "Recent Experiments of the Brothers Wright"; in 1913 a familiar name F. Handley Page on "The Comparison of Monoplanes and Biplanes with special reference to the Stresses in each Type"; the Third Wilbur Wright Memorial Lecture by Prof. G. H. Bryan in 1915 on "The Rigid Dynamics of Circling Flight"; in 1918 "The Wind Channel—its design and use" by J. R. Pannell; "Review of Airscrew Theories" by Major A. R. Low in 1922; "The Work of the Aeronautical Research Committees' Panel on Scale Effect" by W. S. Farren in 1924; in 1926 "Aero Engine Fuels of Today and Tomorrow" by Colonel, The Master of Sempill; "Experiments of Model Airscrews at High Tip Speeds" by G. P. Douglas in 1928 and in 1929 "The Flutter of Aeroplane Wings" by R. A. Frazer—the birds have given place to other fluttering wings and the amateur scientist to the professional.

*January 1955 *Journal of the Royal Aeronautical Society.*

One of the earliest of the scientific writers is Bryan, whose first article, already mentioned, was followed by a paper before the Society on "The Longitudinal Stability of Aeroplane Gliders." Another great name is that of Lanchester who published his famous theory of flight based on the vortex theory in 1894 in a paper read before the Birmingham Natural History and Philosophical Society and read a paper on the Wright and Voisin types of flying machine before the Society in 1908.

1909-1911 were years of growing pains and in 1911 a completely revised set of rules was passed; the technical grades of Fellow, Associate Fellow and Student were created and the composition of the Council was laid down. At least half the number had to be technical. The 'Objects' of the Society were re-defined and greatly extended most significantly to include *inter alia* 'Protect the interests of the Aeronautical profession by conferring a technical status on those qualified for such distinction' and 'Encourage technical students who adopt the Aeronautical profession for their careers.'

The more recent activities show the growing sense of responsibility of the Society as the professional body for Aeronautics, although the link with the non-professional is still carefully fostered, in keeping with a great tradition. The examination for Associate Fellowship was established in 1922; it was frequently revised to improve the standard, finally by the syllabuses of April 1953 to be equivalent to a good Honours Degree. Advancement to the Fellowship has been strictly limited in the past, but it may be necessary to overhaul our ideas somewhat. I shall say a little more about this later.

The recipients of the awards of the Society show forth the evolution of the Society, and indeed of aviation, in the clearest manner; as an example the Society's Gold Medal, which is the highest honour the Society can confer for work of an outstanding nature in Aeronautics, was first awarded in 1909 to Wilbur and Orville Wright "in recognition of their Distinguished Services to Aeronautical Science" and most lately, in 1955, to Lord Hives "for his outstanding work in the field of Propulsion of Aircraft." An admirable brief account of all the Society's awards is contained in a very recent publication*; it will be seen that they now cover many aspects of professional eminence and skill. Our joint meetings with the Institute of the Aeronautical Sciences of America—a body which so gladly acknowledges its debt to this Society and to Laurence Pritchard in its foundation and its organisation—held every other year since 1947, illustrate the point I am making in a striking manner. They have become the recognised forum for the exchange of views on outstanding problems between aeronautical engineers and scientists on both sides of the Atlantic.

The Society has a responsibility for the dissemination and exchange of information and ideas among the members of the Society and others. This has been long and honourably discharged by the reading and publication of papers on all aspects of the subject in the *Journal*, the promotion of Symposia and discussions, the holding of Exhibitions, the establishment and maintenance of a really excellent Library, the establishment of Branches (a lasting monument to Laurence Pritchard, who initiated the scheme in 1925), which now enables 24 groups, widely distributed over these islands (and in Singapore where a Branch was formed in 1953) to hear and discuss the latest developments from those best qualified to speak.

Even more significant was the establishment in 1949 of Divisions of the Society in Australia, New Zealand and South Africa, each with its own Divisional Council and its own Branches.

Since 1940 the Society has published Data Sheets. I think we owe their initiation to a suggestion from Mr. B. S. Shenstone, now a Member of Council and Chief Engineer of British European Airways. The Data Sheets in Structures, Aerodynamics, Performance, Fuels and Lubricants contain, in a form directly applicable to design, information digested from many widely scattered sources of theory, research and practical experiment, many extremely difficult of access. They have proved of great practical value and the sale is world-wide. In parallel, the Society has organised the issue of Monographs on specialist subjects primarily to bring the vast accumulation of knowledge during 1939-1945 into current use by the aeronautical profession. These services are essentially professional, responsible and clearly the result of a well-informed policy. I emphasise this in contrast with the amateur, speculative and necessarily limited scope of the Society in its earlier years. The change is almost revolutionary, but I like to think, and I am sure it is true, that the old eager, pioneering spirit remains, constantly inspiring further advances.

The phases of development and change of the Society are readily distinguished.

THE FIRST PHASE we may call the Victorian, entered into with complete confidence in the ability of man to master the art and science of aeronautics as it had so brilliantly in so many other fields during the Victorian era. The Society essentially amateur, limited, one might almost say semi-private, but none the less attracting some of the most distinguished scientists of the day. This phase lasted for 30 years until 1896 when the Society had reached a very low ebb.

THE SECOND PHASE, the re-Birth 1896-1910; a period of growing understanding of the fundamentals of flight, of practical experiment with kites, models, gliders, in free flight, and some work with artificial air currents. Such great names as Hargrave in Australia, Pilcher, Cody, Bryan, Lanchester in England, Langley, Chanute, the Wright Brothers in America, the Lilienthals and Prandtl in Germany, Ader, Farman and Blériot in France, appear in this phase. Many of them men of deep intuitive power who developed

Royal Aeronautical Society Year Book 1955 - 1956.

a "feeling" for the air which was to bear fruit later.

THE THIRD—the Transitional phase 1910 to, say, 1923, during which we had the Great War 1914-18 and the establishment of a new industry and a new science and art in aircraft design, construction and flying. This phase saw the clear emergence of the profession of aeronautics and of the Society as the representative body, although still without clearly defined professional standards. The Mond Chair of Aeronautics was established in Cambridge, England, in 1919, and the Zaharoff Chair of the University of London in 1923.

THE FOURTH PHASE, 1923-1948, Growth and Development to Professional Status. The most important phase in the Society's life so far. Strength in aeronautics finally became vital for survival; this Society and its Members served their country with distinction during the Second World War; one remembers with pride the Royal Aeronautical Society Advisory Committee, set up by Lord Brabazon, which reported to him and successive Ministers of Aircraft Production on special problems needing professional judgment of the highest standards of integrity and competence, and the special Conferences with the armed Services with their complete trust in the Society and its staff in matters of security.

THE PRESENT PHASE—Incorporation 1949— . The great starting event of this phase is the Charter of Incorporation granted to the Society under Letters Patent by H.M. King George VI, our Patron, on 17th January, 1949. This is a historic date; it established this Society as a Body Corporate and made our rights and responsibilities clear and manifest. We shall—

> "be by virtue of these Presents one Body Corporate and Politic by the name of the 'Royal Aeronautical Society with which is incorporated the Institution of Aeronautical Engineers' and by the same name shall have perpetual succession and a Common Seal with power to break, alter and make anew the said Seal from time to time at their will and pleasure and by the same name shall and may sue and be sued in all Courts and in all manner of actions and suits and shall have power to do all other matters and things incidental or appertaining to a Body Corporate."

These are basic rights with which we are now privileged; they are matched by no less basic and grave responsibilities and it fits well with my argument this evening to remind you of some of them.

> "The objects and purposes for which the Society is hereby constituted are the general advancement of Aeronautical Art, Science and Engineering and more particularly for promoting that species of knowledge which distinguishes the profession of Aeronautics.
>
> "to facilitate the exchange of information and ideas amongst the members of the Society and others,
>
> "to hold meetings of the Society for reading and discussing communications and lectures bearing upon Aeronautical Art, Science and Engineering (and upon subjects relating thereto),
>
> "to establish, form and maintain libraries and collections of models, designs, drawings and other articles of interest in connection with the development and improvement of Aeronautical Art, Science and Engineering,
>
> "to encourage invention and research,
>
> "to establish sections and branches of the Society in the British Commonwealth,
>
> "to provide and award medals and prizes for contributions to the advancement of Aeronautical Art, Science and Engineering,
>
> "to give the Legislature and any departments thereof and public bodies and engineering institutions and others, facilities for conferring with and ascertaining the views of members of the Society and other persons engaged in the profession of Aeronautics as regards matters directly or indirectly affecting Aeronautical Art, Science and Engineering and to confer, send representatives to and communicate with all or any such authorities and bodies in regard to same,
>
> "to do all other things incidental or conducive to the attainment of the Society's objects, provided always that no part of the property or funds of the Society shall be applied for other than charitable objects."

There is no restriction here to handicap us in our further growth and development.

I have still to answer the question posed earlier in this address—"how does our Society propose to keep pace with this phenomenal growth in the practical application of aeronautics?" But before doing so let me give you an extract from an article by the Earl of Halsbury, Managing Director, National Research Development Corporation, taken from an article "Stocktaking on the Research Front" which was published in the "F.B.I. Review" dated March 1955.

> "Three, however, namely atomic energy, jet propulsion and radar, have exercised and will continue to exercise an influence far wider than their immediate field of application would lead one to suppose. In these examples it is necessary to discriminate clearly between what research, with its associated development, produces directly by way of a marketable product, and what it accomplishes indirectly by its reaction on general industry. Aeronautical engineering is, for example, the most technologically advanced and difficult branch of engineering. Apart from defence aircraft, the civilian component of the industry engaged in making passenger aircraft and their engines is small compared with some of our traditional industries, and though it provides a very profitable source of exports, its total turnover would probably be regarded as an uneconomic return on the huge defence research expenditure which it exploits in its

design and incorporates in its know-how. Increasingly, however, this industry first tackles, then solves and finally dominates the solution of problems which no other branch of engineering would have an incentive to attempt. Its results react back on and influence the general engineering industry so that by remaining in the forefront of aeronautical engineering we keep our position in the forefront of general engineering."

This recognition of the advanced nature and deep influence of our professional work, by a great authority, sets the scene well for what I have still to say.

I have attempted to show you, however roughly, how this Society of ours has evolved to be a Chartered Professional Body Corporate; I have quoted from our Charter to illuminate our great responsibilities to our profession, responsibilities over a wide and growing field of art, science and engineering. The level of our work has been assessed by a great authority; it is no less clear from a consideration of the place, the prime place, of aeronautics in the national defence, and its great and rapidly growing contribution to transport and the development of the new resources lying untapped in the remote areas, almost unapproachable lacking air power and most certainly unworkable.

And what conclusion does one draw from all this? Speaking as one privileged and honoured to be your President for a brief twelve months, I think the conclusion is clear. Our Society must move forward; it must advance in such ways as will bring steadily increasing prestige and status to match, serve and adequately to represent the profession of aeronautics, which itself advances and widens in an almost breathtaking manner. We must have constantly before us the objective to become one of the major professional scientific and engineering bodies in this country and to advance our objective by all the means in our power. Nothing short of this is sufficient for the professional level of our work nor for the importance of aeronautics in the national interest. But this advance will not result from actions by the Council alone; it must be supported by a loyal and enthusiastic membership.

Such an advance must rest on many factors; first and foremost our professional gradings and, leading to these, educational standards readily recognisable and interpretable throughout the country. In particular we must have our own Higher National Certificate in Aeronautics. For many years we have accepted the Higher National Certificate in Mechanical Engineering with endorsement for aeronautical subjects, but as a Chartered body this is no longer satisfactory. I mentioned earlier the higher standard for the Associate Fellowship examination introduced recently; this is a good level of scholastic attainment and will be retained, thus ensuring an adequate basic training for our professional gradings of Graduate and Associate Fellow. The Fellowship of the Society at present is awarded only to those who have attained a considerable degree of technical eminence in the profession of Aeronautics. There has been expressed the view that this definition is in practice restricting the promotion of many who are fully qualified for the senior grading in a professional body. It is argued that the terms of the definition of the grade of Fellow imply that this grading is an honour in addition to a recognition of technical standing. I am glad to tell you that the Council has appointed a small but representative Committee to examine this matter and action on their findings will be taken as soon as possible.

Secondly, if our Body Corporate is to be fully representative we must increase our membership. In fact, a drive for membership has already been initiated on the widest basis, and all are invited to help. The immediate aim is to double our membership during the next five years. Our strength in this country is only about a quarter of those available for membership now, so that our objective is very modest. It would, in my view, be to the advantage of aeronautics as a whole to have within one organisation all those concerned with the technical aspects of the subject. We could readily assimilate as Sections, those bodies who now operate independently, we think to our mutual advantage.

Thirdly, we must have a home and Lecture Hall of our own. No. 4 Hamilton Place, which we owe to the foresight and wisdom of a small group of enthusiasts led by Sir Roy Fedden, ably backed by Laurence Pritchard, held on lease—where we have been so happily established since 1939—is rapidly reaching bursting point, and we must have increased accommodation fairly soon. But if we are to achieve that status and prestige necessary to discharge our responsibilities under the Charter, I am convinced that we must have our own place, even if it involves the step of acquiring a site and erecting a new building. We must take the large and long-sighted view in this matter and go forward with courage and with resolution. I shall return to this subject before I conclude.

Other matters need attention, for example, the Lecture Programme. I suggest we should now introduce Commemorative (and endowed) Lectures for the great ones of the past. Lanchester, Henry Royce, Bryan, spring to mind at once. In time these, each an honour to the lecturer and an occasion in itself, would form our main programme backed by Section Lectures, widened from the existing usage to cover the full range of aeronautical activities. In passing, I draw your notice to the great success of the "named" lectures run by the Branches, the "Pierson Memorial" by Weybridge Branch (the initiators of this practice), the "Barnwell Memorial Lecture" by Bristol Branch, the "Sir George Cayley Memorial Lecture" by Brough Branch (following the suggestion of Robert Blackburn, lately deceased), the "Mitchell Memorial Lecture" by Southampton Branch.

In advancing the Society's professional standing we must not forget the wider responsibility for the "general advancement of Aeronautical Art, Science and Engineering"; the Society must be at one and the same time professional and representative of the art and practice not excluding activities which might still be classed as amateur. The Branches of the Society which, while pursuing the same aims and objects, are autonomous and free to admit non-professional and lay members, are admirably suited to help in the discharge of this

wider responsibility and their work is of the greatest value.

In this catalogue of "musts" I have left to the end the most fundamental point; in growing and developing let us ensure that we retain those high standards of professional integrity and disinterested care for the good of aeronautics and its further advancement, which have always distinguished this Society.

To sum up, our Society—an amateur foundation—has now reached maturity as a Chartered Professional body. We recognise the challenge of our new responsibilities under the Charter of Incorporation and in relation to the primary place now occupied by aeronautics in defence, transport and the exploitation of new untapped resources. I have suggested a number of objectives, some in the broad and others more detailed. It appears to me that time measured by human standards shortens with increasing age. From the point reached by myself, ten years seems not very long. Let us see to it then that by 1966, our Centenary year, we shall have acquired the stature appropriate to the work of this Society. Let us go forward with enthusiasm and resolution for the good of aeronautics and all that depends upon it and for peace. And to give point to this I am authorised by the Council to launch here and now a Centenary Fund to be devoted to the acquisition of a fitting house for the Society to come into use by 12th January 1966.

A final word. Our Society is entering another phase in its development, which will carry it forward to a new leadership arising from new and greater responsibilities. Whether we like it or not, we must pioneer the way in even more difficult fields of pure and applied science. As in the past, but in greater degree, our work will set the pace and give the lead over a widening range of Science and Art. Let this be the inspiring background to our service to aeronautics and to our membership of this Society which has given so great a heritage and offers so rich a field for our continued loyalties.

My grateful acknowledgments are due to the Secretary and members of the staff who have assisted me with some of the factual information given herein, particularly Miss Barwood.

List of Past Presidents and Chairmen of Council of the Society

1866-1895	President:	His Grace the Duke of Argyll, K.T.
1896-1897	President:	In abeyance
	Chairman:	Major H. C. Roberts
1897-1898	President:	In abeyance
	Chairman:	Major H. C. Roberts
1898-1899	President:	In abeyance
	Chairman:	Major H. C. Roberts
1900-1907	President:	Major B. F. S. Baden-Powell, Hon.F.R.Ae.S.
1908-1911	President:	E. P. Frost, Esq.
1912-1918	President:	In abeyance
	Chairman:	Major-General R. M. Ruck
1919-1920	President:	The Rt. Hon. The Lord Weir of Eastwood, P.C., F.R.Ae.S.
	Chairman:	Brigadier-General R. K. Bagnall Wild, C.M.G., C.B.E.
1920-1921	President:	The Rt. Hon. The Lord Weir of Eastwood, P.C., F.R.Ae.S.
	Chairman:	Air Commodore H. R. M. Brooke Popham, C.B., C.M.G.
1921-1922	President:	The Rt. Hon. The Lord Weir of Eastwood, P.C., F.R.Ae.S.
	Chairman:	Lieut.-Col. M. O'Gorman, C.B., D.Sc., F.R.Ae.S.
1922-1923	President:	The Rt. Hon. The Lord Weir of Eastwood, P.C., F.R.Ae.S.
	Chairman:	Professor L. Bairstow, C.B.E., F.R.S., F.R.Ae.S. (Now Sir Leonard Bairstow)
1923-1924	President:	The Rt. Hon. The Lord Weir of Eastwood, P.C., F.R.Ae.S.
	Chairman:	Lieut.-Col. A. Ogilvie, C.B.E.
1924-1925	President:	The Rt. Hon. The Lord Weir of Eastwood, P.C., F.R.Ae.S.
	Chairman:	Lieut.-Col. H. T. Tizard, A.F.C., F.R.Ae.S. (Now Sir Henry Tizard)
1925-1926	President:	The Rt. Hon. The Lord Weir of Eastwood, P.C., F.R.Ae.S.
	Chairman:	Air Vice Marshal Sir Sefton Brancker, K.C.B., A.F.C., F.R.Ae.S.
1926-1927	President:	Air Vice Marshal Sir Sefton Brancker, K.C.B., A.F.C., F.R.Ae.S.
	Chairman:	Colonel The Master of Sempill, A.F.C., F.R.Ae.S.
1927-1930	President:	Colonel The Master of Sempill, A.F.C., F.R.Ae.S. (Now Lord Sempill)
1930-1934	President:	C. R. Fairey, Esq., M.B.E., F.R.Ae.S. (Now Sir Richard Fairey)
1934-1936	President:	Lieut.-Col. J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.P. (Now Lord Brabazon)
1936-1938	President:	H. E. Wimperis, Esq., C.B., C.B.E., M.A., M.I.E.E., F.R.Ae.S.
1938-1940	President:	A. H. R. Fedden, Esq., M.B.E., D.Sc., M.I.Mech.E., M.I.A.E., M.S.A.E., F.R.Ae.S. (Now Sir Roy Fedden)
1940-1942	President:	Griffith Brewer, Esq., Hon.F.R.Ae.S.
1942-1944	President:	A. Gouge, Esq., B.Sc., F.R.Ae.S. (Now Sir Arthur Gouge)
1944-1945	President:	A. H. R. Fedden, Esq., M.B.E., D.Sc., M.I.Mech.E., M.I.A.E., M.S.A.E., F.R.Ae.S. (Now Sir Roy Fedden)
1945-1947	President:	Sir Frederick Handley Page, C.B.E., F.R.Ae.S.
1947-1949	President:	H. Roxbee Cox, Esq., Ph.D., D.I.C., B.Sc., F.R.Ae.S. (Now Sir Harold Roxbee Cox)
1949-1950	President:	Sir John Buchanan, C.B.E., A.M.I.Mech.E., F.R.Ae.S.
1950-1951	President:	Major G. P. Bulman, C.B.E., B.Sc., F.R.Ae.S.
1951-1952	President:	Major F. B. Halford, C.B.E., F.R.Ae.S.
1952-1953	President:	G. H. Dowty, Esq., F.I.A.S., Hon.F.C.A.I., M.I.Mech.E., F.R.Ae.S.
1953-1954	President:	Sir William Farren, C.B., M.B.E., M.A., F.R.S., M.I.Mech.E., Hon.F.I.A.S., F.R.Ae.S.
1954-1955	President:	Sir Sydney Camm, C.B.E., F.R.Ae.S.

Special Note: On 19th April 1921 the Council unanimously elected Major-General Sir R. M. Ruck as the first Vice-President of the Society under the new rules in recognition of his long service and devotion to the Society's interests.

Major B. F. S. BADEN-POWELL, *Honorary Fellow*

(1860-1937)

Founder of the "Aeronautical Journal", which celebrates its Sixtieth Birthday with this issue

AN APPRECIATION

by

J. LAURENCE PRITCHARD, *Honorary Fellow*

"A man of hope and forward looking mind"

Wordsworth.

FOR FIFTY SEVEN YEARS Baden F. S. Baden-Powell was part of the history of the Aeronautical Society. He was elected a member of it on 21st April, 1880, when he was just twenty years old. In 1886 he became a member of Council and served on it without a break for a quarter of a century. In 1896 he became Honorary Secretary, and in 1900 was elected President, a position he held for eight years, when the usual order of things was reversed and he was elected Vice-President. In 1919, just on forty years after he had joined the Society, Major Baden-Powell was elected an Honorary Fellow. He died on 3rd October, 1937.

That is a record without parallel in the Society's long history, and one little known in any detail. It is not possible to give more than a passing reference to much that he did and was interested in during his long and very active life, for he was a man of exceptional energy, a characteristic of his family. His brother, Lord Baden-Powell, became founder of that astonishing world movement, the Boy Scouts.

In 1880, the year he joined the Society, "I witnessed my first ascent," Baden-Powell wrote some years later in his book *Ballooning as a Sport*, "and got to know some of the aeronauts of the day. In that year I joined the Aeronautical Society— which, by the way, was then rather laughed at, because the members would talk in a dreamy way about flying machines instead of devoting themselves to the practical and existing appliance, the balloon!"

From that year the young Baden-Powell was well and truly inoculated with air fever. In June 1880 a Commander Cheyne, late of the Royal Navy, who had a wide experience of Arctic expeditions, read a paper before the Aeronautical Society that received great publicity. He put forward a scheme for going to the North Pole by balloon.

B. F. S. BADEN-POWELL

"Several ascents were organised with the idea of testing the suitability of balloons for Arctic use," records Baden-Powell, who was himself now taking a very lively and active interest in balloons, "and during this boom 'The Balloon Society' was started. In 1881 the subject began to grow in interest, military ballooning

was for the first time in England being developed, and Captain Templer was making a name for himself."

Captain Templer had recently been appointed one of the organisers of the newly-formed Army Balloon School. He did much for military ballooning as well as for the development of man-lifting kites and for the first British Army airship, which was flown by Colonel Capper and S. F. Cody in 1907. Templer was a member of Council for the years 1881 to 1896, and was one of those members who helped to save the Society from extinction on the death of Brearey, the first Secretary.

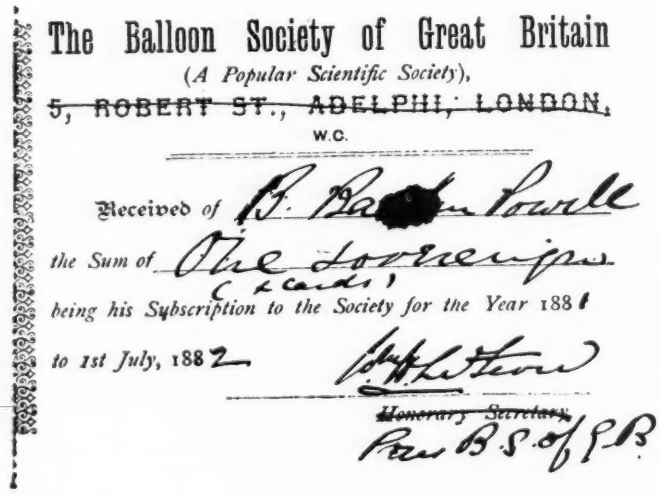
"The Balloon Society," recalled Baden-Powell, "determined to give a Balloon Garden Party at Lillie Bridge in 1881, and hired Simmons, the professional aeronaut, to make an ascent in his new indiarubber balloon."

The Balloon Society set an example which was followed successfully by the Aeronautical Society nearly seventy years later. There were great rivalries between the two bodies for some years. Baden-Powell was a member of both. In his life he was a supporter of most of the bodies formed to encourage any particular aspect of aeronautics.

"I at once secured a place in the car, and was early on the scene," continued Baden-Powell. Not only was he early on the scene, but he was so thrilled by his experience that he afterwards bought a balloon for himself, and made many trips in it, as well as taking up his friends.

In 1882 he joined the Scots Guards. Few army subalterns in those days were actively interested in anything so far-fetched as a possible war in the air. From very early days, though, Baden-Powell was convinced that the country which held the mastery of the air would be master of the world.

He came from an adventurous and inquiring stock. His mother was descended from that great Elizabethan adventurer, Captain John Smith, the first Governor of Virginia. His father, a Professor at Oxford, suggested small balloons for scientific use with the fatal Arctic expedition of Sir John Franklin, so Baden-Powell was early put on the far from straight and narrow path of aeronautical navigation.



The Balloon Society of Great Britain
(*A Popular Scientific Society*),
~~5, ROBERT ST., ADELPHI, LONDON,~~
W.C.

Received of B. Baden Powell
the Sum of One Sovereign (2 cards)
being his Subscription to the Society for the Year 1881
to 1st July, 1882
John W. Letts
~~Honorary Secretary~~
Pres. B.S. of G.B.

BALLOON SOCIETY OF GREAT BRITAIN,
(A POPULAR SCIENTIFIC SOCIETY.)
ANNUAL SUBSCRIPTION—FIVE SHILLINGS.
OFFICES:—26, *BUDGE ROW, CANNON STREET, E.C.*
W. H. LE FEVRE, C.E., President.

LILLIE BRIDGE GROUNDS, WEST BROMPTON.

The President and Council of the Society request the pleasure of seeing
B Baden Powell
AT A BALLOON GARDEN PARTY,
On Saturday Afternoon, the 30th July at 3 o'clock.

NOTE.—Gentlemen and Ladies desiring to become Members of the Society, are invited to leave their names with the President, or send them by post to the Office.

Major Baden-Powell's invitation to the Balloon Garden Party and (*below left*) his receipt for his subscription to the Balloon Society for the year 1881-2—the days of the golden sovereign!

As a regular soldier he put the chief value of the conquest of the air as a military one. The year he joined the Army found him taking part in a vigorous public discussion on the dangers of ballooning, which he blamed largely on the carelessness of organisers and pilots. The following year, 1883, at the brave and confident age of 23, Baden-Powell lectured before the Royal United Services Institution on Military Ballooning.

The years 1882 and 1883 were indeed full of excitement for the adventurous and inquiring young subaltern. Of those years he wrote,

> "In 1882 Colonel Burnaby*, who had already done a good deal in the aeronautical line, and was on the Council of the Aeronautical Society, succeeded in crossing the Channel in a balloon. This created further interest in the subject. Sir Claude Crespigny hired Mr. Simmon's balloon to attempt a similar feat, but an unfortunate accident at the start, in a violent wind, resulted in a broken leg and other injuries to Sir Claude, and Mr. Simmons was shot off in the air by himself. A remarkable Channel crossing was the result, for the aeronaut stated that it only took him twelve minutes to go from coast to coast! This would imply a rate fully two miles a minute, or 120 m.p.h!"

Hurricane Hazel must have read Baden-Powell's note about that Channel trip!

One must give Baden-Powell a considerable amount of praise for his nerve to face a military audience to lecture on military matters when he had only been in the Army a year. As it turned out the lecture was an able one, at a time when it was not the orthodox view to believe there was much in the air where the Army was concerned. And unorthodox views were no more popular than they are nowadays. His historical survey of military ballooning up to the date of his lecture,

*Famous for his ride across Russian Asia on horseback, described in his book *A Ride to Khiva*.

1st June, 1883, shows that he had read widely and profitably. In his introductory remarks he boldly declared, "It seems surprising that a body of aeronauts does not form a regular branch of every civilized army."

He lectured in the centenary year of the invention of the balloon and promptly rubbed it into his listeners that only ten years after Montgolfier had sent the first hot air balloon into the sky, the French had begun aeronautical research at Meudon and that the following year a regular balloon corps was formed.

"In October 1795, an aeronautic school was established at Meudon, composed of sixty pupils, who were instructed in all details of the construction and management of balloons as well as in all scientific subjects relating thereto."

It was not until July 1862, pointed out Baden-Powell, that "the first military balloon experiments in England took place at Aldershot." Nine years later, in June 1871, a Committee was appointed to enquire into the use of balloons in warfare, although it was not until 1879 that an official Balloon Committee was appointed to carry out experiments.

Baden-Powell seized every opportunity of going to see anything which could go up in the air. The French had long been experimenting with dirigibles. Before his lecture he had gone over to Paris to see the airship of the brothers Tissandier, so that he could report on it. The following year he was back again in France to see the fish-shaped "La France" of the French Army at Meudon, the experiments with which are very fully described in the *Annual Report* of the Society for 1885.

This trip to Meudon roused an interest which Baden-Powell never lost. In later years he lectured and wrote papers on the subject and visited Germany, France and the United States to see airships. I have before me a brief tabulated record of a few of his visits.

> "In 1899 went to Friedrichshafen and spent two days going carefully over the Zeppelin Works and watching the construction of No. 1 Zep.
>
> "1903 went to Paris to see Santos Dumont's airships. Also went over the Lebaudy works.
>
> "Went to United States and the St. Louis Exposition, 1904, where about four different airships were tried.
>
> "Watched all the developments of the Barton airship; also the Spencer (fitted with an engine designed by Baden-Powell). Saw the original Willows airship at Cardiff.
>
> "1909 went to Frankfurt Aeronautical Exhibition, where the 'Parseval' made daily ascents. Visited the aviation meeting at Rheims, where the 'Col. Renard' and 'Zodiac' airships made ascents.
>
> "1912 to Berlin Aero Exhibition, and to Bitterfeld and over the Parseval works."

These names mean little to a modern generation totally unaware of the real delights of airships. I have always believed, and indeed still defiantly believe, that a cruise in an airship can beat anything the aeroplane can offer, scenery, entertainment, quiet, comfort. Baden-Powell was enthusiastic enough to design a model dirigible, 40 feet in length, filled with hydrogen, in later years. It was driven by a model engine.

His trip to France in the late summer of 1884 was his last sight of an airship for some time, for he was really jolted down to earth by being sent by the War Office to take part in the Nile Campaign, riding a camel!

Late in 1886 he was elected a member of Council of the Society, its youngest member. There is an interesting letter from Brearey, the first Honorary Secretary of the Society, written to Baden-Powell at the beginning of this year.

> "I have had no occasion since I wrote to you, to call the Council together—or rather since I received your letter of consent," wrote Brearey. "My present note is to inform you that on the 12th January is the 20th anniversary of the Society, which was instituted at a meeting at the Duke of Argyll's, and that I have made a proposition that we mark the event by a dinner."

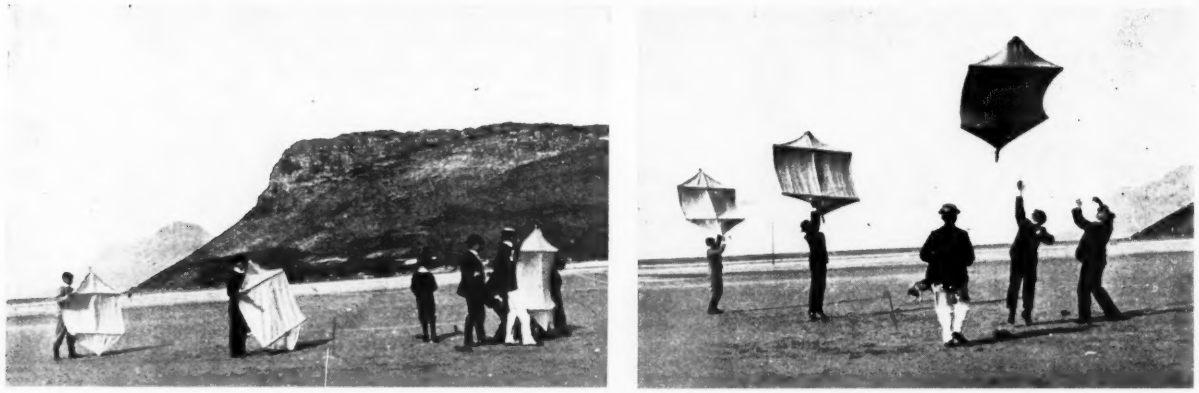
This year we celebrate the 90th anniversary. I have always hoped that 12th January would be celebrated annually by some function open to all members, something to which they could look forward, which would symbolise, too, that they belonged to the pioneer Society of the Air Age. I had always hoped, too, that it would be the day when the President would review the past year's work of the Council and its Committees, and tell of the achievements by the Society's members; when he would outline the achievements yet to come, the paths of research yet to be trod, and hold out "Every Tomorrow a Vision of Hope." But somehow the hope has not fructified.

It was, by the way, at the 1886 Annual Meeting of the Society that Captain Griffiths' paper, "Jet propulsion for aeronautical purposes," was read.

Although asked by the Council to read a paper at the next meeting of the Society, Baden-Powell was for the next few years as far removed from the Society as it was possible to be. He went to Queensland, Australia, as A.D.C. to the Governor, during which time he campaigned in New Guinea and travelled in Java and Borneo. The result of these years was his book, *In Savage Isles and Settled Lands*, bearing the formidable subtitle, "A personal record of personal experiences in Europe, Egypt, Ceylon, India, Australia, New Zealand, New Guinea, Java, Straits Settlements, Borneo, Tonga, Samoa, Sandwich Isles and the United States."

Before he left England Baden-Powell had begun inquiries into the possibilities of lifting a man into the air by means of kites. He wrote to Henry Coxwell, who, with James Glaisher held the world's height record for more years than any others have ever done, suggesting that kites might be substituted for captive balloons for military purposes by raising an observer into the air.

In 1894 he carried out the successful trial trip of the Army war balloon, the "Duchess of Connaught," from



The method of starting the Baden-Powell man-lifting kites.

Aldershot, and then seriously turned his attention to the kite problem. At his home at Pirbright it is recorded in the *Aeronautical Journal* for April 1897, in a paper on Man-lifting war kites, "The first well-authenticated occasion on which a man was raised by a kite was on January 27, 1894 when Captain Baden-Powell, Scots Guards, conducted some experiments at Pirbright Camp with a huge kite 36 feet high." This kite had a lifting surface of some 500 sq. ft.

By May 1895 he felt that he knew enough to lecture on the subject to the Royal United Service Institution. He asked Lord Methuen* to take the Chair. Methuen replied "I am quite ready to take the Chair on the 22nd, and recommend anyone, except myself, to go up with your kites."

It was Lord Methuen who said of the R.U.S.I. at Baden-Powell's lecture,

> "If it has any claim on the Army and Navy, and it has a very great claim, it has none so great as this, that every fad and every invention can be brought forward here by military and naval officers alike; that they can put forward their inventions, they can have them discussed by naval, military, and civilian alike, and that they will get a good and patient hearing; and many an invention, which is quite in its childhood, has gained its existence simply from being well argued in institutions such as this."

Baden-Powell's child of the air received a rough reception from the balloonatics, for he had asserted with great confidence that the kite would replace the balloon for observation purposes, and that would never do, for it would have put balloon enthusiasts out of their jobs.

The first speaker, Lt. R. B. Blakeney, of the Balloon Section of the Army, certainly couldn't agree. The second speaker roundly declared, "I made a great many experiments with kites during last summer, and thought the matter over to a certain extent during the winter, and I have come to the conclusion that there is not much in it."

In fact all the speakers disagreed with the lecturer and Lord Methuen wound up the proceedings by saying, in no uncertain terms, that he wasn't satisfied as to the safety of kites.

Baden-Powell was not easily put off by uncomplimentary criticisms. He had plenty of that during his life, when he put forward ideas. That September he demonstrated his kites before the meeting of the British Association at Ipswich.

> "The weather was not very favourable for an ascent, the breeze being of the lightest description," reported *The Times*. "Nevertheless, Lieutenant Baden-Powell and subsequently two other individuals were easily raised to a height of some 50 ft."

Later in the year Baden-Powell went up over 100 ft., and in a paper in the *National Review* for December 1895 he vigorously championed afresh the use of kites for observation purposes. The previous autumn he had kept a weight of 9 stone flying all day long at Pirbright camp, at a height of 300 ft. When he lectured before the Society of Arts in 1898, he had a more appreciative audience.

Brearey had died at the beginning of 1896 and it looked very much as though the Society would cease

The first man-lifting experiments.

*Joined Scots Guards 1864, commanded Methuen's Horse in Bechuanaland Expedition 1884-85; commanded 1st Army Division in Boer war, etc. and became a Field-Marshal in 1911.

to exist, for the membership was almost a negligible quantity, not a couple of score altogether. Brearey had always been convinced success would come and it was his constant thought to keep the Society going, however few the stalwarts were. He had approached several members to take over his papers and Society material in case of his death, and they were duly sent to E. A. Barry, one of the senior members of the Council. Late in 1896 Barry managed to get together a meeting of the Council.

It was a thin meeting. Besides Barry there were present only Baden-Powell and E. P. Frost (who afterwards became President). Six members of the Council out of the eleven listed at the death of Brearey, had sent in letters of resignation! There was only £5 5s. 0d. in the kitty. At this meeting of the dauntless three, one proposed, one seconded, that the third, Baden-Powell, should be asked to act as Honorary Secretary and keep the bridge between the aeronautical past and the future.

Baden-Powell accepted the challenge and for that inspired decision of hope alone, he deserves a special place in the long history of the Society.

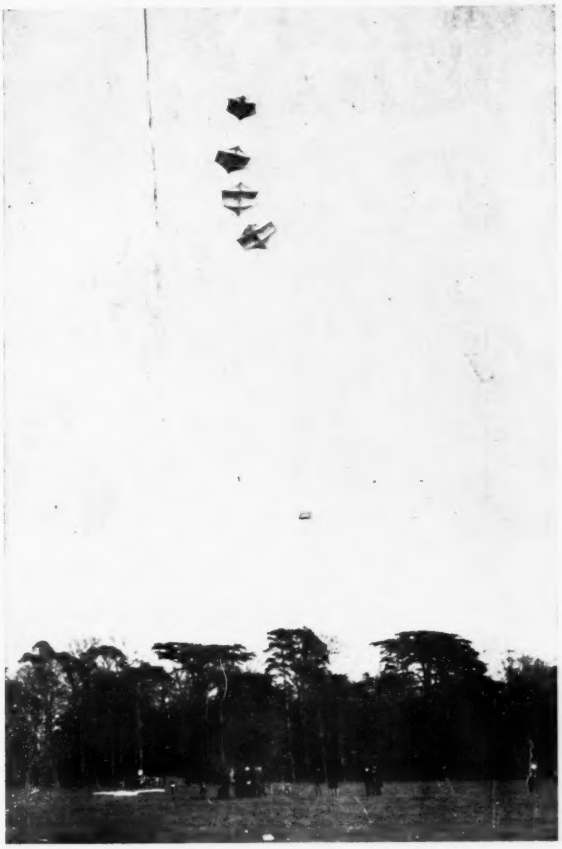
He called a meeting at his own house twenty days later, and announced that Hiram Maxim, Major J. D. Fullerton and Sir Edwin Arnold had agreed to serve on the Council. He explained that he had written to many of the leading scientists and prominent people suggesting they should join the Society. One answer which he received is produced facsimile, for it is a classic. It is dated 8th December, 1896, just seven years before the Wright Brothers made their first flight. It reads,

> " Dear Baden-Powell, I am afraid I am not in the flight for ' aerial navigation.' I was greatly interested in your work with kites but I have not the smallest molecule of faith in aerial navigation other than ballooning or of expectation of good results from any of the trials we hear of. So you will understand that I would not care to be a member of the Aeronautical Society. Yours truly, Kelvin."

Baden-Powell was then writing his paper " The Conquest of the Air," which was to be published in the April 1897 issue of the *Royal United Services Magazine*. It gives a different point of view and provides its own comment.

> " The object of this article is to show that aerial navigation is now no mere wild dream, but will very probably form a prominent feature in the next great war . . . What will the good citizens of London say when they see a hostile dynamite-carrying aerostat hovering over St. Pauls? Our naval supremacy would be comparatively useless if we had no aerial force. It therefore becomes not only desirable for us to have aerial machines for offence, but it becomes *necessary* for us to possess them for defence against hostile attack through the air, and the speediest and handiest machine will win the day."

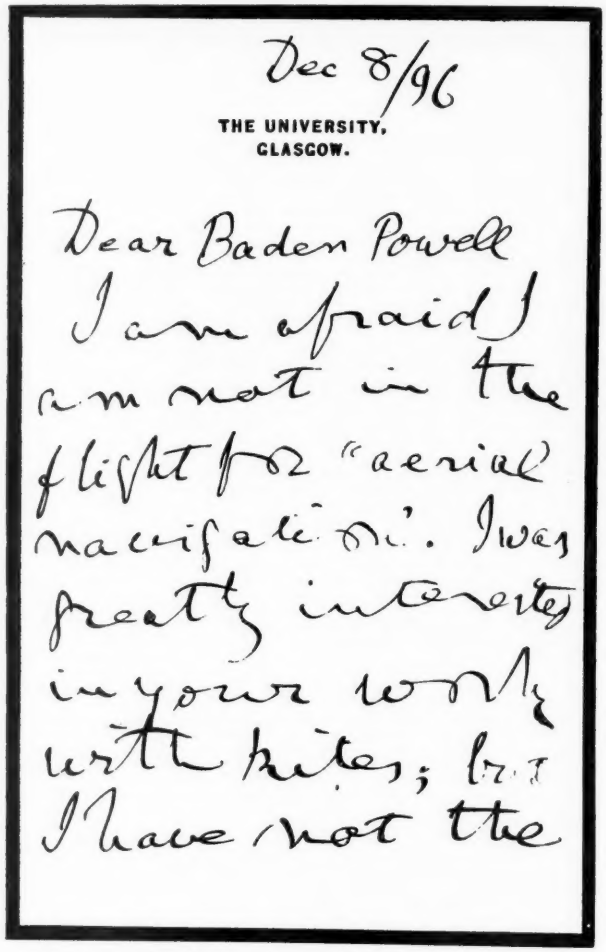
At the December 1896 meeting of the Council, when only four members were present, Messrs. Roberts, Frost, Barry, and Baden-Powell, it was resolved that a quarterly *Journal* should be issued. In a letter to Lt. Colonel Lockwood Marsh, Secretary of the Society, on 5th February 1923, Baden-Powell wrote,



A man being lifted at Aldershot in 1895 by Baden - Powell's kites.

> " It may interest you to know how it started. When we resuscitated the Society we suggested publishing some sort of *Journal*—to continue the *Reports*—but there was only about half a dozen members and no money. So we discussed ways and means, and it was suggested that some of us should subscribe together to bring out a *Journal*, but this should be a private affair and the Society should not be saddled with the expense of it. I think we also hoped that in time we might recoup ourselves. . . . . However, of course, it never paid and gradually it drifted into becoming the property of the Society. But that is why we did not call it *The Transactions* or any such title. We called it the *Aeronautical Journal* in imitation of the *Geographical Journal*. But these things are soon forgotten."

At the March 1897 meeting the Hon. Secretary reported a balance of £15 and a membership of 39, including four non-paying honorary members. The annual subscription still remained at one guinea, as it had been from 1866. An extract from the March Council meeting reads,

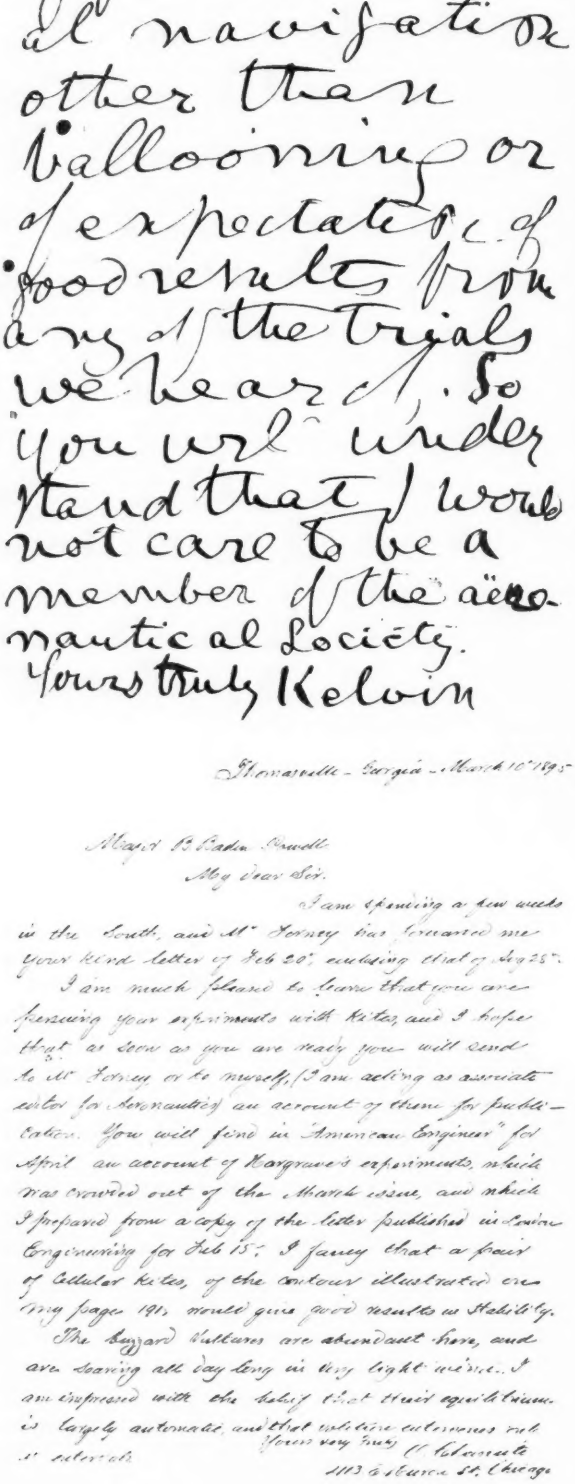


Dec 8/96

THE UNIVERSITY,
GLASGOW.

Dear Baden Powell
I am afraid I am not in the flight for "aerial navigation". I was greatly interested in your work with kites; but I have not the smallest molecule of faith in aerial navigation other than ballooning or of expectation of good results from any of the trials we hear of. So you will understand that I would not care to be a member of the aëronautical Society.
Yours truly Kelvin

(*Above*): Lord Kelvin's reply to Major Baden-Powell's invitation to join the Aeronautical Society (half size). (*See* p. 13.)



Thomasville - Georgia - March 10th 1895

Major B. Baden Powell
My dear Sir.

I am spending a few weeks in the South, and Mr. Forney has forwarded me your kind letter of Feb 20th enclosing that of Aug 28th.

I am much pleased to learn that you are pursuing your experiments with Kites, and I hope that as soon as you are ready you will send to Mr. Forney or to myself, (I am acting as associate editor for Aeronautics) an account of them for publication. You will find in "American Engineer" for April an account of Hargrave's experiments, which was crowded out of the March issue, and which I prepared from a copy of the letter published in London Engineering for Feb 15th. I fancy that a pair of cellular kites, of the contour illustrated on my page 191, would give good results in Stability.

The buzzard Vultures are abundant here, and are soaring all day long in very light winds. I am impressed with the belief that their equilibrium is largely automatic, and that volition intervenes only at intervals.

Yours very truly,
O. Chanute
1113 E. Huron St., Chicago

(*Left*): A letter from Octave Chanute which reads:

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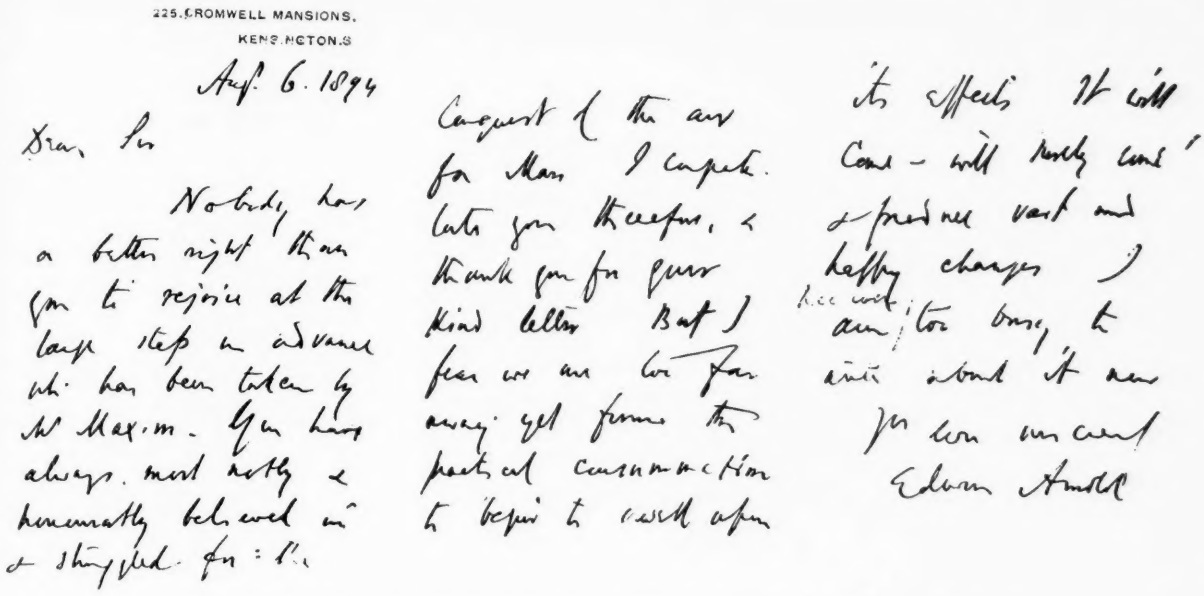

225, CROMWELL MANSIONS,
KENSINGTON, S

Aug. 6. 1894

Dear Sir

Nobody has a better right than you to rejoice at the large step in advance which has been taken by Mr. Maxim. You have always most nobly & honourably believed in & struggled for the Conquest of the air for Man. I congratulate you therefore & thank you for your kind letter. But I fear we are too far away yet from the practical consummation to begin to dwell upon its effects. It will come—will surely come! and produce vast and happy changes. I am however too busy to write about it now.

Yours ever sincerely,
Edwin Arnold

A letter from Sir Edwin Arnold, dated 6th August 1894, to Major Baden-Powell, which reads:—

"Dear Sir,

Nobody has a better right than you to rejoice at the large step in advance which has been taken by Mr. Maxim. You have always most nobly and honourably believed in and struggled for the Conquest of the air for Man. I congratulate you therefore and thank you for your kind letter. But I fear we are too far away yet from the practical consummation to begin to dwell upon its effects. It will come—will surely come! and produce vast and happy changes. I am however too busy to write about it now.

Yours ever sincerely,
Edwin Arnold."

(Sir Edwin Arnold became famous for his epic poem *The Light of Asia*. He was a schoolmaster in India, returned to England and became editor of *The Daily Telegraph*).

"The Society did not possess sufficient funds to provide a suitable quarterly Journal without outside support. However the Honorary Secretary suggested issuing the Journal entirely at his own expense and risk."

For the first three years, indeed, Baden-Powell bore the greater part of the burden of the *Journal*. It may be of interest to quote actual figures. On a scrap of paper found among Baden-Powell's papers he had made rough notes summarising the finances of the *Journal* from 1897 to 1899. The usual number of copies printed was 300. The total cost for those years was £211 7s. 3d. and the total receipts £72 15s. 6d. The Council voted £48 toward the cost over the years, leaving the rest to be paid privately. Of it Baden-Powell contributed the largest portion.

Today the number printed of the *Journal* is 9,750 and the receipts and expenditure accounts are published for all to see.

On receiving the first number of the *Aeronautical Journal* the Editor of *Invention* wrote an article which I would have liked to have quoted in full. He had been the Editor for many years of the famous *Mechanics Magazine* to which Sir George Cayley and many others had contributed on the subject of aerial navigation. He had known all those who had first joined the Society in 1866 and for the first five years or so of its existence he had regularly recorded its proceedings.

"A copy of the first number of the new issue of the *Aeronautical Journal*," he wrote, "carried us back only a generation, to the time when the Aeronautical Society was a power in the land; when it had a good practical Council, good meetings, good papers, good exhibitions, in fact, when all was sound and substantial about it. But it retrograded, languished, pined, and all but resolved itself into a mere memory of the past."

In 1899 Baden-Powell sailed for South Africa on the outbreak of the Boer War, and E. S. Bruce became the Honorary Secretary.

"The Council whilst accepting with regret the resignation of Major Baden-Powell take the opportunity of recording the very valuable services rendered by him to the Society, which he virtually re-established from the time he accepted the Honorary Secretaryship by his inaugurating the new quarterly *Aeronautical Journal*."

Bruce had been asked by Brearey to take on his work after his death.

The Beacon Goldsworth
Woking Surrey 30th Sep 1899

Major Jno, or Baden Powell —

Dear Sir yours of yesterday's date came promptly to hand. I had not received any letter previously. The Editor of the "English Mechanic" repeatedly gives notices that he will not forward letters to correspondents, as most of them do not wish their addresses to be known — so the Ed. may be excused —

I very much appreciate the considerate offer of the Council of the Aeronautical Society to enrol me as an Honorary Member, which position I shall be proud to accept: but I must state, that I cannot promise to attend the meetings as I am now in the 76 year of my age, but I have not lost interest in Aeronautics as I have recently been giving attention to the subject again, and trying some experiments tending to practical results. These I have embodied in a paper which I had some thoughts of sending over to my American friends. Do you now publish periodical reports? as I do not wish what I have written to be shelved —

You are perhaps aware that I was one of the original promoters of your Society and many years on the Council. I sent in my resignation principally for this reason. Your late Hon. Sec. (deceased) patented a fantastic idea of a flying machine consisting of a long waving sheet, and was offended at me for not praising it as being the right thing for ensuring ultimate success. I got letters from others blaming me for not condemning the scheme and so have saved them some hundreds of pounds which they had been induced to invest and so lost by the patent. This was very annoying to me especially as there were threats of a law suit in which I was required to give evidence.

Fifteen years ago I retired from business and bought ten acres of land on the top of this hill, on which I built a residence. The spot would serve for a gliding flight, but is so wooded with large trees and evergreens which cause such eddying currents of wind that I find much difficulty in getting a steady breeze for out door experiments.

Faithfully yours
F. H. Wenham

A letter from F. H. Wenham which reads:—

The Beacon Goldsworth
Woking, Surrey, 30th Sep. 1899

"To Major Baden - Powell

Dear Sir,

Yours of yesterday's date came promptly to hand. I had not received any letter previously. The Editor of the *English Mechanic* repeatedly gives notices that he will not forward letters to correspondents as most of them do not wish their addresses to be known—so the Ed. may be excused.

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Faithfully yours
F. H. Wenham."

" At that time I did not see my way to undertake so serious a duty," declared Bruce in an account of the Society which he gave to La Société Francaise de Navigation Aerienne de Paris in 1900. " Shortly after Brearey's death the Council asked Major Baden-Powell to accept the post and with the energy characteristic of the Baden-Powell family he rapidly infused new life into the Society, increased the quantity and quality of its members, enlarged the Council and developed the quarterly *Journal*."

In South Africa he had little opportunity to follow his aeronautical interests, although it is recorded that some use was made of his man-lifting kites for raising Marconi wireless apparatus. He had followed the work of Marconi very closely and spent much time with him during his early experiments. The smug comment of one of the newspapers was " The services rendered by Major Baden-Powell illustrate how useful it is for a British officer to have a hobby in peace time of more practical value than polo or billiards."

While still in South Africa he was elected President of the Society and on his return to England became very active again in the aeronautical world. On 4th December 1902 he gave his Presidential address to the Society on " Recent Aeronautical Progress." Two days before he had taken the Chair at the Council, when it was announced that for the first time in its history the Society was renting an office of its own and was starting a library for the use of its members. The membership had risen to 100 and the balance in the Bank was £204.

Baden-Powell's Presidential address has been widely and often quoted, and was reprinted by the Smithsonian Institution in Washington. He told his hearers of the work of Lawrence Hargrave in Australia; of that of the Wright Brothers, and Chanute and Samuel Langley in the United States of America; of the dirigibles of Zeppelin, Santos-Dumont and others; and surveyed the progress while he had been away in general terms. He left his hearers with the confident hope that the air age was only just a little time ahead. Twelve months later, indeed, that confident hope was fulfilled.

He spoke of the Society and its future, words which still stand.

> " I may here seize the opportunity of explaining to our visitors and others the objects of our society, and why it is we make so much of a study which to them may seem somewhat chimerical and of no very special merit, and by explaining these I hope to enlist their sympathy and support to the movement. For I have before now been asked 'Why should it be necessary to have a society for the study of aerial navigation? Where is the importance of it? Why not institute a society for submarine navigation, for wireless telegraphy, or for the encouragement of any other novel invention for the improvement of means of communication or warfare?' But useful as many such inventions may be, none can have the great importance which may some day be attached to the machine which navigates the air. . . .
>
> " We have to study the subject of aerodynamics, the effect of air pressures on plane or curved surfaces travelling at various speeds and at various angles of incidence. We have to investigate the efficiency of aerial propellers of different forms, the strengths of materials, the energy and weights of various forms of motors. Then we must also study the natural currents of air, the variability of air strata, the trends of winds and so on. The great range of subjects to be gone into by our Society is thus patent."

Baden-Powell was the first to announce the recent progress of the Wright Brothers and he did so in this address, in convincing detail.

> " I received a letter only a few days ago from Mr. Chanute," he said. " He says that he had just returned from witnessing this season's gliding experiments of the Brothers' Wright and that they have made a very considerable advance since last year, and now glide at angles of 6° to 7° sustaining 125 to 160 lb. per horsepower. Wright is now doing nearly as well as the vulture, is not far from soaring flight, and I am changing my views as to the advisability of applying a motor."

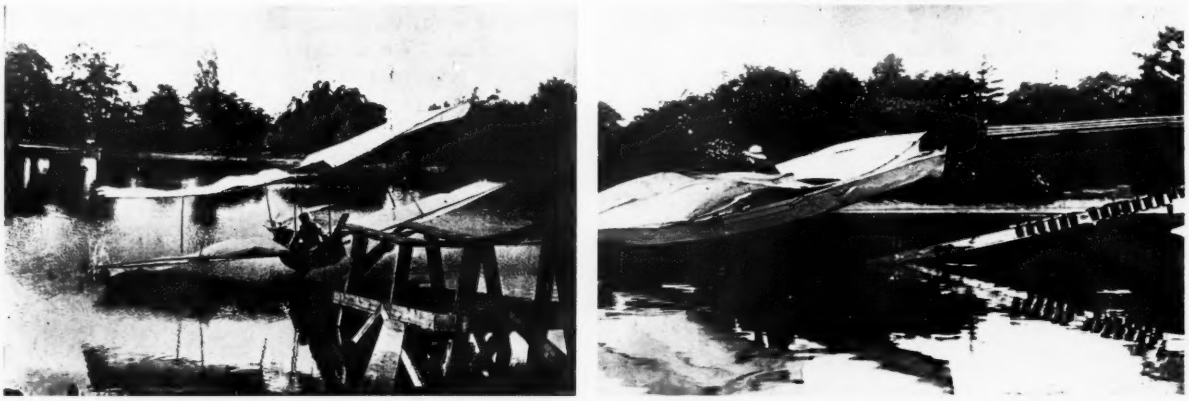
What a thrill those words must have given many of those present, coming with all the authority of their own President and Octave Chanute, whose own experiments had been attracting much attention. In the *Journal* for December 1953 there was printed a facsimile of the attendance sheet, and there can be seen the signatures of Hiram Maxim, Griffith Brewer, E. P. Frost (later President of the Society), Patrick Alexander, Alec Ogilvie, C. S. Rolls and many others.

Baden-Powell not only wrote to many aeronautically-minded people, but went to see what they were doing. He was one of the witnesses of the work of Horatio Phillips with his remarkable venetian blind machine; of Maxim and his great machine at Baldwyn's Park; of Pilcher and his gliding experiments. He was unhappily present when Pilcher had his fatal accident. He watched Zeppelin fly in his first dirigible and saw the flights of the French Lebaudy and Santos Dumont dirigibles. He saw the early flying in France, flew himself with Wilbur Wright, went to the great Rheims meeting and the many meetings in England.

He received a disappointing setback about his man-lifting kites. S. F. Cody had been experimenting for some years, was a far greater showman of his wares, and the War Office finally decided in favour of his kites. Cody patented his form of construction in 1901, seven years after Baden-Powell had lifted himself 30 feet in the air with one of his own kites, and Cody's biographer, G. A. Broomfield, wrote, " The design had possibly been influenced by the work of Hargrave and Major B. F. S. Baden-Powell."

In 1904 Baden-Powell made some interesting experiments in gliding technique, for he had come to the conclusion that the simplest way to gain initial gliding speed with safety was to launch his glider down an inclined track finishing over a sheet of water.

The Crystal Palace authorities allowed him to build a water chute at the edge of one of the lakes in the Palace grounds. The glider consisted of a flat-bottomed



The gliding water-chute experiments at the Crystal Palace in 1904.

boat, about 20 ft. in length and 2½ ft. beam, which slid down on wooden rails. The boat was fitted with flexible wings, both biplane and monoplane, constructed with thin cambric stretched over a bamboo frame.

A number of glides were made, though none of them very long. Baden-Powell was helped by J. T. C. Moore-Brabazon (now Lord Brabazon of Tara). Maybe the latter was getting in some practice for the Cresta Run!

Later in the year, in a paper on " The Development of the Aeroplane," which he read before the British Association at their meeting in Cambridge, Baden-Powell briefly described these interesting experiments which, however, did not reach any conclusive stage. The same year he designed and had constructed a light petrol engine for aeroplanes, which he exhibited at the St. Louis Exposition.

Baden-Powell was a born experimenter and was not deterred by failure. Hope sprang eternally in his breast. He was an example of " Man never is, but always to be blest " as far as aviation was concerned. He worked like a beaver at his ideas, hoping that out of the mass of figures he accumulated that he would be able to solve the great secret. The Society has a number of his notebooks which are filled with sketches of model gliders, of paper, wood and fabric, proposed aeroplanes and helicopters, ideas for airscrews, and notes of experiments made and those to be made. These notebooks provide mute evidence of the incredible industry of their owner, an industry worthy of a greater degree of success than he obtained. Like many experimenters of the time he was lacking the fundamental training and data which were essential for success, and hoped that by trial and error he would hit on the answer. With him, as with most experimenters like him, there was too little trial and too much error.

He missed no opportunity to lecture on aviation, to write papers on the subject, to write to all those interested and to many who were not. He filled his notebooks with data from all sources. When he lectured or wrote, he seldom failed to draw attention to the Society and the advantages of becoming a member of it.

This year, 1904, was one of great interest. In addition to his Crystal Palace experiments and his paper to the British Association, he visited the St. Louis Exposition, together with two of the leading members of the Society. It was the first official representation of the Society in the United States.

" Our Society was well represented," he reported. " Colonel Capper and Mr. Walter Reid both took a prominent part in the meetings of the Aeronautic Conference and also on the Jury in the Kite Competition."

All three damned the organisation of the Exposition, but all three learnt the great value of making such visits and learning what the other man was doing. Capper took the opportunity to visit the Wright Brothers, with whom he and Mrs. Capper became very friendly, and at the Society's meeting on 2nd December 1904 he said

> " From the experience we gained we can all do a great deal more in the way of experimenting with gliding machines in this country than has been done . . . I shall be very much surprised if we do not hear from America before long of a gliding machine driven through the air by a motor. I am not at liberty to give any details on the subject, but I shall not be surprised if we hear of that being practically done..."

In fact Capper was well aware of what the Wrights were doing for in a letter (25th November 1905) Orville Wright wrote to the British Military Attaché in the U.S.

> " At the request of Lt. Colonel Capper we gave the British government the first chance to secure the use of our invention to foreign countries. . . But the progress of the later negotiations has been such as to make it possible that a crisis will be reached before the British War Office has all the obtainable information before it and is ready to reach a decision as to whether it will take up the flying machine at this time."

Baden-Powell could not stop himself writing about aviation. For many years he was the Editor of *Knowledge and Illustrated Scientific News*. It did not pay its way, but Baden-Powell had many good friends.

like Frank McClean and Dr. W. J. S. Lockyer, who encouraged him to keep going and showed their practical help by paying some of the bills. After he had failed to sell it to Pearsons in 1904 Baden-Powell had printed a supplement, *Aeronautics* and in 1907 issued it as a separate publication under the editorship of himself and J. H. Ledeboer. Unfortunately the aeronautical slump which followed the First World War was too severe for the pocket of its owner and it was closed down in 1921. But in *Knowledge* and in *Aeronautics* there is much recorded which might otherwise have been lost of those exciting and stimulating pioneering years.

On 4th August, 1908, Baden-Powell wrote to the War Office to say that he was constructing an aeroplane "which is now nearly ready for trial," and would they consider buying it for £2,000? I feel there were considerable streaks of naivety in his make-up.

The Director of Army Contracts replied by forwarding a copy of the specification for a Military Flying Machine, and of the tests and general conditions which would have to be fulfilled before the machine could be accepted and paid for. They are historic documents.

The letter from the War Office was dated 4th September 1908. The American contract with the Wrights was published nine months previously, on 23rd December 1907, as required by United States law, so the British War Office would have had a copy when it issued its own specification and tests to Baden-Powell.

The American contract agreed to pay £5,000 for any heavier-than-air machine capable of carrying two people weighing in aggregate 350 lb., with petrol sufficient for 125 miles, at a speed of 36 m.p.h. The issue of the contract was criticised severely in America, as the War Department was supposed to have lost its head! Fifteen days after the British War Office sent a copy of its specification to Baden-Powell, Orville Wright flew for 58 minutes at Washington. The date, 19th September, 1908.

The British Specification is given here in full.

"SPECIFICATION FOR MILITARY FLYING MACHINE."

1. The machine must have carrying capacity sufficient to carry
   (*a*) Operator. Average weight 170 lb.
   (*b*) Observer. Average weight 170 lb.
   (*c*) Instruments, maps, etc. Average weight 10 lb.
   (*d*) Fuel for a journey of four hours.
2. It must be capable of rising from or descending on to any fairly smooth ground of an area of 10 acres, without damage to itself or occupants.
3. It must have an average speed when in the air of not less than 25 miles an hour in a calm, which speed it shall maintain for not less than one hour.
4. It must be capable of rising with its full load to a height of 2,000 feet above its starting point, and be able to carry its full load at height of 5,000 feet above Mean Sea Level.
5. It must be reasonably steady when under flight, in order that observation with field glasses may be made from it.

The staging for the gliding experiments at the Crystal Palace.

6. It must be capable of remaining in the open in all ordinary weather for a period of one month without very material deterioration.
7. It must be capable of flights of 2 hours duration during which it must describe various circles of varying diameters.
8. It must be capable of being kept in the air "hovering" or "circling" over any desired point, for periods of a minute or more.
9. It shall be so constructed that if the engine stops from any cause, or any portion of the machinery breaks down, there shall be a reasonable chance of the occupants reaching the ground in safety.
10. It must be so constructed that the consumption of its fuel will not upset its stability during flight.
11. It must be capable of being taken to pieces for carriage on board ship, or on rail, and of being re-assembled at any desired spot, by skilled men, within a period of 72 hours.

Some of the tests for Military Flying Machines, issued with the Specification are worth recording.

Among the flight tests and conditions it was stated:

"The trial ground shall be selected by the War Office, ordinary grass open land of an area not less than 10 acres. There may be hedges such as are usual in most parts of England on all four sides of the plot of ground, but there shall be no continuous rows of high trees, houses or telegraph wires along more than two sides of the plot."

Each candidate had to carry out five flight trials. The conditions for the first flight trial began,

"The machine shall be brought to any point of the trial ground selected by the operator, and pointed in any required direction," and "The operator shall not require any other assistance in order to start the engine or machine. The machine must rise from the ground, and fly round a captive balloon 12½ miles distant, and back to the starting point. The time will be taken at each point. The average pace for the 25 miles to be not less than 25 miles per hour. The pace to be calculated as follows: The rate in miles per hour going to be added to the rate in miles per hour returning, and the sum to be divided by 2."

The second flight trial was an altitude one, round a captive balloon at a height of 2000 ft. The third trial called for a flight of two hours duration " during which it shall describe at least three circles of approximate diameters of 200 yards, ¼ mile and 1 mile." The fourth trial called for a War Office Observer (" accustomed to Captive Balloon work "!) to be taken up for half an hour at least 1,000 ft. and

> " shall proceed in such directions as required by the Observer, and shall ' hover ' or ' circle ' over a point selected by him, for at least one minute."

While this is happening the test instructions add

> " It shall be possible for the Observer to look downwards from his position without his remaining in an unduly cramped attitude."

The fifth flight trial called for flights of five minutes with full tanks, and for the same period with tanks containing fuel for only ten minutes—a stability test. Petrol was calculated at the rate of half a gallon per b.h.p. of the engine.

Under the General Conditions of testing it was noted that machines were required to rise from the ground under their own power " without any special starting devices outside its own construction."

The War Office also had a clause " The Observer or Observers taking part in any flight shall volunteer to take part and shall not be ordered to do so."

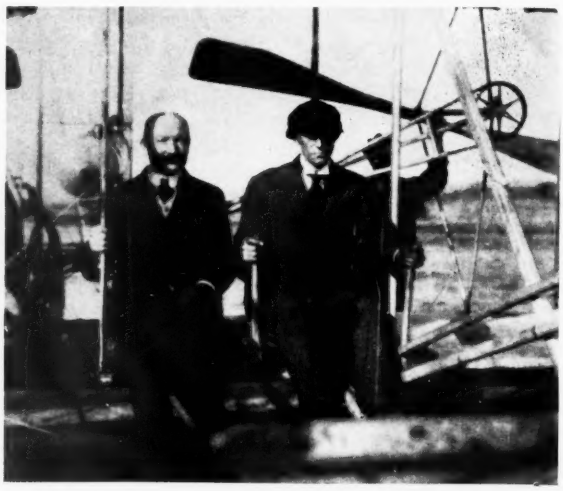
The last clause, Clause 10, is worth being given in full.

> " The operator shall not be required to make ascents (1) In rainy weather. (2) Where there seems to be an early probability of electric disturbances. (3) In winds of over 15 miles per hour, as measured by three flights of a pilot balloon as used in the British Service to determine the velocity of the wind. Note.—The pilots usually take the velocities at heights varying from 50 to 300 feet above the surface of the ground. (4) In the dark, or in twilight. (5) In fog or thick mist."

The years 1908 and 1909 were great years for Baden-Powell. On 8th October 1908 he flew with Wilbur Wright at Le Mans in France, on the same day as C. S. Rolls, Frank Butler, and Griffith Brewer, the first Englishmen to fly. Baden-Powell's flight appears to have decided him to have no further negotiations with the War Office for there appear no further records among his papers. Achievement was far outrunning specification, and Baden-Powell must inevitably have felt that he had seen and experienced a mastery of the air not then reached by any of Wilbur Wright's contemporaries. It was, indeed, a red letter day in his long aeronautical experience.

These years saw an astonishing upsurge in all air matters. Small societies and clubs sprang into existence, most to die almost as quickly as they began. Baden-Powell sprang into the fray and found himself quickly in the middle of acrimonious and noisy discussions, public and private.

In October 1909 he presided at the Mansion House over a large meeting to discuss the formation of a representative National Council to control and encourage aviation in Great Britain. It will give some idea of the spate of air bodies which had come into existence



Major Baden-Powell with Wilbur Wright at Le Mans in 1908.

by the following quotation from *The Times* report. This report does not cover all the representatives there by a long way.

> " Among the societies represented were the Aeroplane Club of Great Britain, the Leicestershire Aero Club, the Northumberland Aero Club, the Midland Aero Club, the Kite Flying Association of Great Britain, the South West of England Aeronautical Society, the Scottish Aeronautical Society, the Sheffield Aero Club and other provincial clubs and societies."

The babel ultimately boiled down to nine times nothing, except for the considerable after heart-burning.

Baden-Powell had circularised the clubs and societies and air organisations in an effort to get a general agreement on what everybody should do in the coming air age. But he found that aeronautics was too aerated a drink to enable those who imbibed it to agree on much. In many respects it is perhaps fortunate for aeronautical progress that agreement is not too easy, although the difficulties may cause much heart-burning at times. I hope they always will.

Baden-Powell this year was a moving spirit in obtaining an experimental flying ground at Dagenham, where members of the Society could have their own machines for experimental flying. The ground was rough and unsuitable, and although a cinder track was prepared from which machines could take off, and sheds for housing machines, the whole scheme proved a failure. It was not, indeed, one which fitted in with the general organisation of the Society. The sheds were ultimately bought by one of today's best known aircraft designers—at a bargain price.

In March 1909 came the Aero Show at Olympia. Baden-Powell showed his 40 ft. model semi-rigid airship and a clockwork aeronautical camera which took photographs at regular intervals, and had a self-recording apparatus to enable the altitude, direction of flight, time and so on, to be noted on each photograph at the time it was taken.

That month *The National Review* published his paper, " Law in the Air." In it he put forward the necessity for a certificate of airworthiness.

> " A mishap in the air, when it does occur, is liable not only to have serious consequences for the machine and its occupants, but may also do considerable damage to persons and property below. It will therefore be very necessary to establish certificates of competancy, which would probably be issued by the Board of Trade or such other body."

Baden-Powell further suggested that the rules for aerial navigation should follow those for navigation at sea, and drew attention to the serious problems created by flying over other countries' frontiers and territory, as well as over private property.

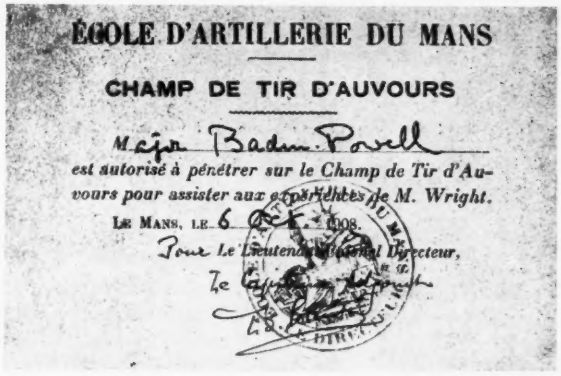
In October he gave the opening lecture of the Session at the Heriot Watt College in Edinburgh on " Recent Progress in Aerial Navigation " with the Lord Provost in the Chair.

I have noted that Baden-Powell went to see any new development or experiment in aviation whenever he could and in this lecture he related one of his experiences when visiting Count Zeppelin.

> " The first time I called he gave me all the information I wanted about the balloon construction and allowed me to take the photographs I am showing now. A year or two later, being in Germany again, I called upon him. He said at once, ' I am very glad to see you again,' and asked me if I played chess. When I answered that I did, he asked me to have a game. We played chess all afternoon and I neither heard nor saw more of the airship. The fact was that the German government had taken up the possibilities of dirigible and were in treaty with the Count."

Baden-Powell left Edinburgh to lecture, a few days later, at the Merchant Venturer's Technical College at Bristol and on 8th December, 1909 he lectured before the Royal United Services Institution on " How Airships are likely to affect war," a lecture which included aeroplanes as well as dirigibles.

The famous Field Marshal Lord Roberts was in the Chair and in his opening remarks, introducing Baden-Powell, he said of flying at that time:


ÉCOLE D'ARTILLERIE DU MANS

CHAMP DE TIR D'AUVOURS

Major Baden-Powell

est autorisé à pénétrer sur le Champ de Tir d'Auvours pour assister aux expériences de M. Wright.

LE MANS, LE 6 Oct. 1908.

Pour Le Lieutenant-Général Directeur,

The military permission which enabled Major Baden-Powell to fly at Le Mans with Wilbur Wright.

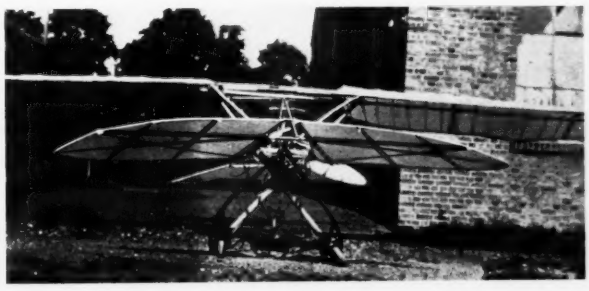
> " Something will be evoked out of all these trials, something which will perhaps astonish those who come after us as much as these present aeroplanes and dirigible balloons have astonished us, I have no doubt . . . I believe that aerial machines will be a great feature in future wars and I am anxious that the country should wake up to the necessity of knowing all about them."

Lord Roberts drew attention to a book he had recently read called " The Valour of Ignorance." His words are as applicable today as they were then.

> " It fits England exactly. It is the ' valour of ignorance ' which pervades the whole country. Our people are very brave and very confident because they know nothing about what is going on. What we have to do is to try and wake up the country; make them understand what is going on in the world."

Baden-Powell made many suggestions in his paper and they aroused a long and interesting discussion from one of the biggest audiences which had yet attended an aeronautical lecture.

One of the speakers was J. W. Dunne who had written to Baden-Powell over five years before, on 27 April, 1904, a very remarkable letter which began, " Though I am well aware of the magnitude of such a



Major Baden-Powell's monoplane The Midge. Structure: American elm, streamlined where exposed. Four main members of bamboos, jointed with short steel connections. Double skids, solid wooden wheels on steel forks with spiral springs. Planes: Elevator 30 sq. ft. on universal joint. Main plane 90 sq. ft. bamboo frame. 25 ft. span, 3 ft. 10 in. chord. Surface pegamoid cloth. Tail plane 20 sq. ft. on bamboo frame. Engine 12 h.p. Buchet. Wooden propeller 5 ft. 6 in. diam. Total weight, including pilot, 350 lb. Price complete, including engine and all fittings, £120. Date 1910.

WILBUR WRIGHT
ORVILLE WRIGHT

CABLE ADDRESS
WRIGHTS, DAYTON O

WRIGHT BROTHERS
1127 W. THIRD STREET
DAYTON, OHIO

22 August 1910

Major B. Baden-Powell.
London.

My dear Major Baden-Powell,

Please accept our thanks for your letter containg particulars of the accident to poor Mr. Rolls. It is exceedingly difficult to fix the cause of such an accident. It may have been caused by some fault of construction or assembling. A pin may have been left unfastened or may have worked loose. I am, however, rather inclined to think that the catastrophe was due to an attempt to descend through a rising trend just in front of the grand stand into the horizontal wind just beyond it. So that the wind caught the machine on top and slammed it into the ground before it could be straightened up. We have had similar experiences when gliding off of a steep ridge. But whatever the cause it is most sad and a great loss to English aviation.

Please accept sincere regards not only from myself but also from my brother and my sister and remember me also to your sister & believe me.

Yours truly
Wilbur Wright

Letter from Wilbur Wright to Baden-Powell on the accident which caused the death of C. S. Rolls.

claim, I am confident that I have threshed out and finally solved the stability in gliding aeroplanes," a claim he brilliantly justified in 1910 when he flew two miles at the Isle of Sheppey without touching the controls. The flight was officially witnessed for the Aeronautical Society by Orville Wright and Griffith Brewer. In those first few months in 1904, before the full work of the Wrights was known, Baden-Powell had discussed at length Dunne's ideas. The correspondence has been preserved and is in the possession of the Society.

One can only give a brief summary of Baden-Powell's major activties in a paper of this nature. Undoubtedly his special interest had been in his kite experiments, and he was very disappointed when the War Office failed to take a more active part when there had been such good prospects of real success. In later years he became President of the Kite Flying Association of Great Britain, of which his great rival S. F. Cody was a member of Council and W. H. Dines, a former President of the Meteorological Society, a Vice-President.

Baden-Powell's energy on behalf of the Society was astounding. He remained at the helm until the aeroplane had become a reality. He knew all the pioneers, many of whose names are now those of history. He corresponded with the famous and the not-so-famous all over the world.

When Brearey died in 1896 the Society had no address to which subscriptions or other communications from members could be sent; and in fact none of the most elementary machinery for running the Society. There was, nevertheless, much going on at the time within the knowledge and experience of Baden-Powell. Hiram Maxim, Horatio Phillips, Percy Pilcher, Octave Chanute, Lawrence Hargrave, Otto Lilienthal and others had aroused interest and anticipation. Early in 1897 (27 February) there was a lecture given at the Royal Artillery Institution, Woolwich, on aviation by a speaker whose work was to have a considerable and lasting impact on aeronautical progress, one who like Chanute, was later awarded the Gold Medal of the Society, Dr. G. H. Bryan.

The decade 1896 to 1906 was a period of pioneering endeavour and success, which gave the ten years which followed a quality which has not been obtained since. These were the years when Baden-Powell played his great part in the Society's history.

In his lecture on Aerial Navigation, which he gave before the Society of Arts on 17th April, 1907, he said,

> "I am one of those who believe we are just about to enter an era of great change in human life."

He lived long enough to see the exciting beginnings of the great change, the pioneering of air transport, the courageous flights across the Atlantic and the Continents of the World, and speeds and altitudes and ranges being reached which had hardly been anticipated by the most imaginative of those who had struggled so long with "jam tomorrow and jam yesterday but never jam today," as it were.

He was a great traveller, and possessed a persistence which some found difficult at times, with a habit of wanting to be in the centre of things aeronautical. Yet he took a firm interest in quite unexpected things. I give one.

In 1910, like many others before him and after him, he believed he had hit on a system to beat the Bank at Monte Carlo, and he wrote to Sir Hiram Maxim about it.

"What you have suggested in regard to roulette is by no means new," replied Maxim, and at some length explained to Baden-Powell how the players must lose, and pointed out that the Bank had been winning a million and a quarter pounds sterling annually for many years.

"However, if you wish to try a system," Maxim ended his letter, "all you have to do is to come to my house. We have a very accurate Paris-made roulette and no one can play better than her ladyship."

In April 1930, Major B. F. S. Baden-Powell completed 50 years as a member of the Society and the following telegram was sent to him from the Society he had cherished so well.

> "Very cordial congratulations Mister past-President from the Council and members of the Society on the 50th Anniversary Monday, the 21st of your membership. Your splendid services to aeronautics and to the oldest aeronautical Society in the world will never be forgotten. Sempill. President."

I quote the words, from the letter of Sir Edwin Arnold to him on 6th August 1904. I could not better them.

"You have always most nobly and honourably believed in and struggled for the Conquest of the air for Man."

This short paper is for remembrance.

MAJOR BADEN F. S. BADEN-POWELL

A CHRONOLOGY

1860	Birth.
1880	Witnessed his first balloon ascent. Joined the Aeronautical Society.
1881	Made his first balloon ascent. Carried out experiments on airscrews.
1882	Entered the Scots Guards.
1883	Lectured on "Military Ballooning" to the Royal United Services Institution. Visited Paris to see the Tissandier dirigible.
1884	Visited French aeronautical station at Meudon and saw the French Army dirigible La France. Late in year sailed to Africa to take part in the Nile Campaign.
1885	In Africa, during Nile Campaign.
1886	Attended German and Russian manoeuvres and reported to British War Office. Elected a member of Council of Aeronautical Society.
1887	Paper "How I learnt ballooning" in *Temple Bar* for March. Began his studies on man-lifting kites.
1888/91	In Queensland, Australia, as A.D.C. to the Governor. Took part in New Guinea with a punitive force and travelled in Java and Borneo. Published his book *In Savage Isles and Settled Lands.*

1893 Began kite experiments. First published record of taking part in Society's lecture discussions.

1894 April. First man to be raised by a kite into the air.
Travelled to West Coast of Africa.

1895 Lecture on "Kites: their uses in War" to the Royal United Services Institution.
Second visit to West Coast of Africa. Sent in full report of French fortifications to British War Office.
Paper in November *Blackwood's Magazine*, "A trip Heavenward."
Paper in December *National Review*, "The aircar."

1896 Becomes Honorary Secretary of the Society.
Attached to Balloon School at Aldershot for kite experiments.

1897 FOUNDS *AERONAUTICAL JOURNAL*.
Paper in *Royal United Services Magazine* for April, "The Conquest of the Air."

1898 Lecture on "Kites. Their theory and practice" in March to the Society of Arts.
Awarded the Silver Medal of Society of Arts.
Paper in *Pearson's Magazine* "War Kites."
Paper on "Balloons for Geographical Research" before the British Association.

1899 South Africa—Boer War.

1900 October. Elected President of the Society while in S. Africa.
Paper on "The Secretary Bird" in July *Aeronautical Journal*.

1901 In South Africa.

1902 Paper in January *Aeronautical Journal* on "War Balloon in S. Africa."
Presidential Address to the Society, December, on "Recent Aeronautical Progress."

1903 Published book *War in Practice*.
Paper in September *The Car Magazine*, "Aeroplanes and Flying Machines."
Paper in September *Illustrated Scientific News*, "Progress with Airships."
Constructed large model airship with 1½ h.p. engine.

1904 Paper in June and July *Knowledge*, "Aeroplane Experiments."
Paper in April *Aeronautical Journal*, "Experiments with screw propellers."
Paper in July *Aeronautical Journal* on his gliding experiments at the Crystal Palace.
Paper to British Association at Cambridge on "The Development of the Aeroplane."
Visits St. Louis Exposition at which he gave the opening paper.
Retires from the Army.

1905 Paper in May *Fortnightly Review*, "Airships and and Santos-Dumont."

1906 Paper in May *National Review*, "The advent of the flying machine."
Paper in the October *The Car*, "In an Italian War balloon."

1907 Paper in *Journal of the Royal Meteorological Society* for July, "The Exploration of the Air."
Published his book "Ballooning as a Sport."
Founded *Aeronautics*.
Lecture to the Society of Arts in April, "Aerial Navigation."
Resigns the Presidency of the Society.

1908 Paper in November *Nineteenth Century*, "The Problem of Aerial Navigation."
Paper in *Aeronautical Journal*, "Experiments with dipping planes."
Elected Vice-President of the Society.
8th October. Flies with Wilbur Wright.

1909 Paper in March *National Review*, "Law in the Air."
Paper in October *Aeronautical Journal*, "Some lesssons from Rheims."
Paper in January *Aeronautical Journal*, "Experiences with the Wright machine."

1910 Designs The Midge light aeroplane.
Edits book of formulae, *Alexander's Aeronautics*.

1911 Lecture in April to Junior Institution of Engineers, "Recent Progress in Aeronautics."

1914/18 Rejoined Scots Guards and fought in France.

1919 Elected an Honorary Fellow.

1930 Fiftieth anniversary of joining the Society.

1937 Death.

The Jet Flap

by

I. M. DAVIDSON, B.Sc., A.F.R.Ae.S.
(*National Gas Turbine Establishment*)

The 960th Lecture to be given before the Society, "The Jet Flap" by I. M. Davidson, B.Sc., A.F.R.Ae.S., was given at the Royal Institution, 21 Albemarle Street, London, W.1, on 20th October 1955 with Mr. N. E. Rowe, C.B.E., D.I.C., F.C.G.I., F.I.A.S., F.R.Ae.S., in the Chair. Introducing the Lecturer, Mr Rowe said: Mr. Davidson was now engaged as a Research Engineer at the National Gas Turbine Establishment; he had been there since it was formed. Born in Glasgow, he studied at Glasgow University and obtained an Engineering Degree with First Class honours. He joined the Aerodynamics Section of the Gas Turbine Division of the Royal Aircraft Establishment in 1943, went to Power Jets Research and Development Ltd. and from there to the National Gas Turbine Establishment. Mr. Davidson had been engaged on special problems for some years and had published papers on supersonic compressors and intakes, compressor blade fouling, high efficiency air cleaning techniques and compressor blade flutter so that his work over the years had covered a fairly wide range.

Introduction

Throughout the animal kingdom powered flight is a surprisingly common attribute and whenever it occurs both the sustenation and the propulsion are provided by the same structural and aerodynamic mechanism. There is, in fact, but a single aerodynamic reaction which is divided, for convenience, into thrust and lift. In earlier times this convention was presumably not recognised, for the ornithopter appears to have formed for some centuries the principal technical basis of man's aspiration to heavier-than-air flight. Of the exceptions, Leonardo da Vinci's helicopter is now, of course, an accepted vehicle, but this lecture is concerned mainly with fixed-wing aircraft for which it is significant that success came only with the aeroplane, or, as Lachmann[1] has recently put it, with the powered glider.

Given that development there grew apace the now classical theories of aerodynamics[2], in the evolution of which it became apparent that the processes of nature could not only be emulated, but in certain directions surpassed. One such example is the study of boundary layer control, while another is the rise of engine aerodynamics; and indeed these two disciplines now bid fair to usher in an era of what has aptly been described[3] as powered lift.

In that field two main trends could hitherto be seen. In one a small fraction of the engine working fluid is so used to control the aircraft boundary layer that the ultimate theoretical performance of an ideal wing can almost, but not quite, be realised. In the other there is the development of the lightweight gas turbine to a state from which its employment for the generation of pure jet lift seems only just around the corner. Thus, there is on the one hand a system in which the thrusting engine plays but a minor role and, in the other, one in which it is wielded as the *force majeure*. There is, in effect, a growing tendency towards the synthesis of the engine with its airframe; but, so far, towards a synthesis which is essentially a design or technological achievement.

Whether such an integration is fundamental or artificial, aerodynamic or structural, may not at first seem important, for so long has the aeroplane now existed that its several unnatural vices are commonly taken for granted. Their magnitude may in some measure be recalled by thinking of the significance during the landing process of the stalling and minimum drag speeds. How many birds are commonly exposed, for example, to a landing hazard, and for what purposes do they employ the stall?

In human and avian flight near the ground there are a great many differences, but of these only two appear vital—that the bird sports a complete mastery over the stall while, with its relatively low wing loading, it can fly much more slowly. In all species flight is naturally a means to an end and for that reason practical aviation is, and always will be, tied to wing loadings of about a hundred times those of the birds. Thus, for a bird-like performance to be possible, one obvious necessity is a means for the generation and control of very high lift coefficients—higher perhaps than anything which has previously been considered possible. The other is, naturally, the removal of the danger of the stall.

In recent years, a possible practical solution of just those difficulties has apparently emerged. This is the jet flap (Fig. 1) which depends upon nothing more than the aerodynamic resynthesis of the lifting and propulsive means, the entire propulsive jet being ejected in the form of a thin, full span sheet from the trailing edge of the wing. Although novel, the underlying physical principle is by no means new, for it is commonly found as a side effect in experiments on boundary layer control by blowing over the top surface of a trailing edge flap. Indeed, in that guise it enjoys world wide recognition, the American term being supercirculation and the French, hypersustentation.

The first published information was that contained in a paper written by Hagedorn and Ruden[4] at Hanover in 1938. In France the discovery was made independently, the first trace being an unpublished paper written in 1942 by Valenci, Parigi and Borgel[5] at Marseilles. The first relevant French publication was by Poisson-Quinton[6] in 1948 while, as recently as December 1954, Jousserandot[7] has described the results of extensive experiments in which the active principle was all but isolated.

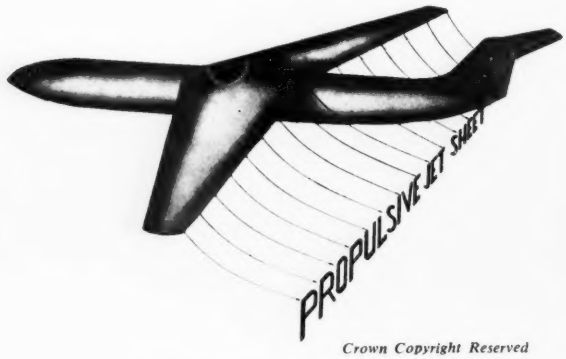


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FIGURE 1. A jet-flapped aircraft.

In the U.S.A. the effect was demonstrated as early as 1931 by the early results of Bamber[8], but there, as elsewhere, the emphasis was on the use of the jet for boundary layer control. The British trail is again a long one for, at the Royal Aircraft Establishment, the subject was broached by Lyon, Barnes and Adamson[9] in 1941, and again by Mettam[10] in 1951.

However, in all the early works the vital principle seems to have been considered mainly as a scientific curiosity, and the crucial step was not taken until November 1952. That step was the observation by Constant that, the propulsive jet of a modern aircraft being a very powerful physical entity, it should be one hundred per cent. combined with the wing in flight near the ground.

PART I
The Basic Principles

1. The Lift on a Two-Dimensional Wing

Basically, the gas stream from a jet flap acts just like a large Fowler flap. It baulks the lower mainstream, forces it over the wing and so, following Bernoulli, aerodynamic lift is generated. This argument is simple enough, but it implies that the jet path is already known; that there is in fact a worthwhile downward penetration of the mainstream. Among other things, the effect must clearly depend upon the speed of the aircraft and the setting of throttles so that there is, as with the ornithopter, some inexorable combination of the lift and the thrust. To discover the laws of that combination it is best to consider the mechanism in two-dimensional flow.

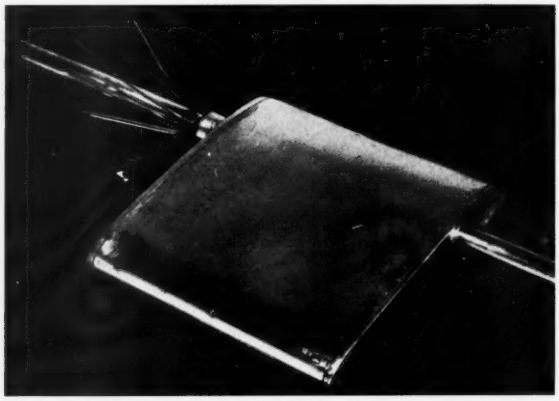

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FIGURE 2. The original 5-inch model.

1.1. THE DEMONSTRATION EQUIPMENT

In the first instance testing was restricted to the model illustrated in Fig. 2, this being run in a 5 in. by 15 in. tunnel constructed of plywood, "Perspex" and paper, by the scientific staff. For obvious reasons, the results of those exercises are best forgotten, but they did serve a useful purpose in pointing the way. For example, a rapid series of tests in which the jet was composed of hydrogen and nitrogen in differing proportions showed at once that variations in the jet

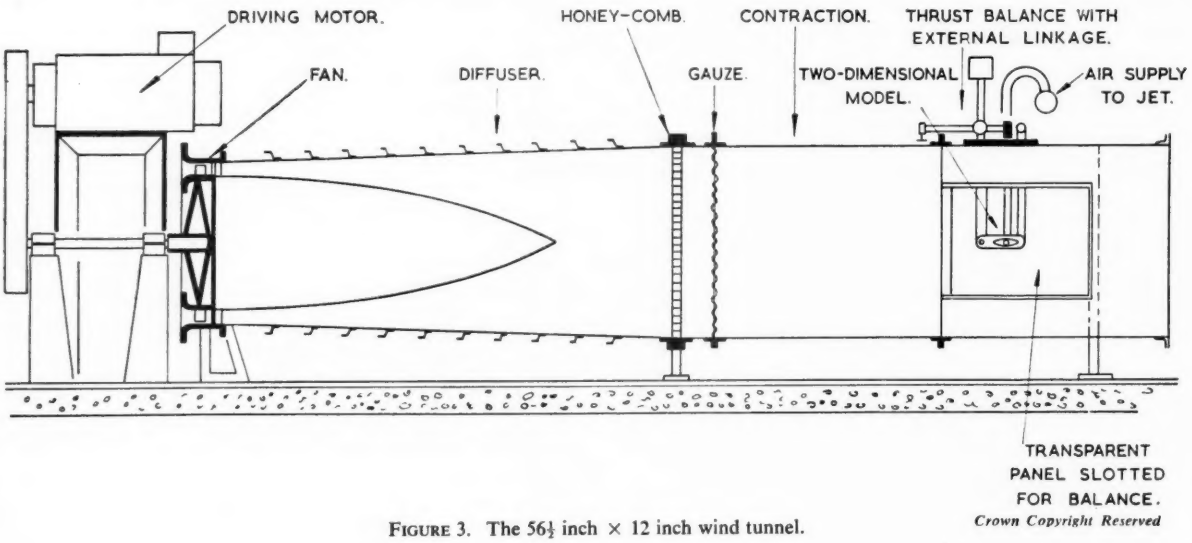

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FIGURE 3. The 56½ inch × 12 inch wind tunnel.

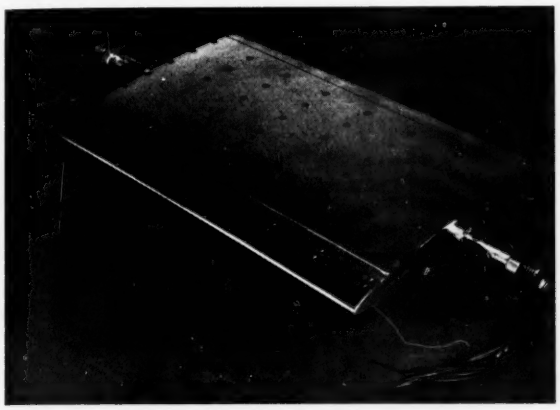

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FIGURE 4. The 8-inch elliptical model.

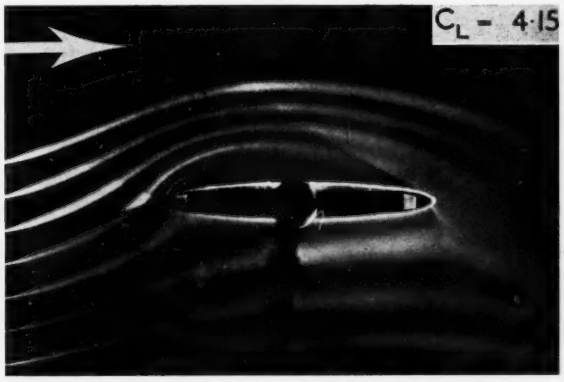

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FIGURE 5. A typical two-dimensional flow.

density and velocity were not of much consequence. All that seemed to matter was its thrust.

When some progress had been made with the theory so that it was possible to predict roughly the sort of effects which would be observed, a short experimental programme was designed around an old low speed cascade tunnel which had, in the meantime, been modified for the purpose. The general arrangement is shown in Fig. 3, the settling chamber being 56½ in. square, the working section 56½ in. by 12 in., and the maximum speed about 115 ft./sec. In all about eight or nine models were tested, but several of these were in the nature of ranging shots and need not therefore be discussed. The bulk of the work was done on the elliptical aerofoil of Fig. 4, this really representing three models in that separate trailing ends were available with respective jet angles of 31·4°, 58·1° and 90·0°. The types of flow which were observed are well illustrated by the smoke photograph of Fig. 5, in which the jet coefficient, C_J, is precisely analogous to the conventional coefficients C_L and C_D. That is, it is simply the total jet reaction, J, in pounds divided by the dynamic pressure, $\frac{1}{2}\rho V^2$, times the wing area.

Although a relatively accurate thrust-drag balance was constructed, the lift and moment could be measured only by pressure plotting, the detailed distribution of the relevant static pressure holes being shown, together with the jet slot position, in Fig. 6.

1.2. THE LIFT AND CENTRE OF LIFT

The basic aerodynamic mechanism is illustrated in Fig. 7, where it is essential to distinguish between the engine thrust or total jet reaction, J, and the reaction thrust, $J\cos\theta$, on the aerofoil. Since, with or without mixing, the jet must be turned to flow parallel to the flight path and since it carries everywhere a momentum flux equal to J, each of its elements must exert a centrifugal force as shown. In turn, this force is balanced by a difference of static pressure across the jet such that the total lift on its centre line is equal to $J\sin\theta$, the original downward momentum flux. In the theory use is made of the idea of an analogous structural flap, shown dotted and, from the size which this can assume, it will be seen that very high lift coefficients must in principle be possible (*see* Fig. 8).

In practice it is best not to divide the lift into an

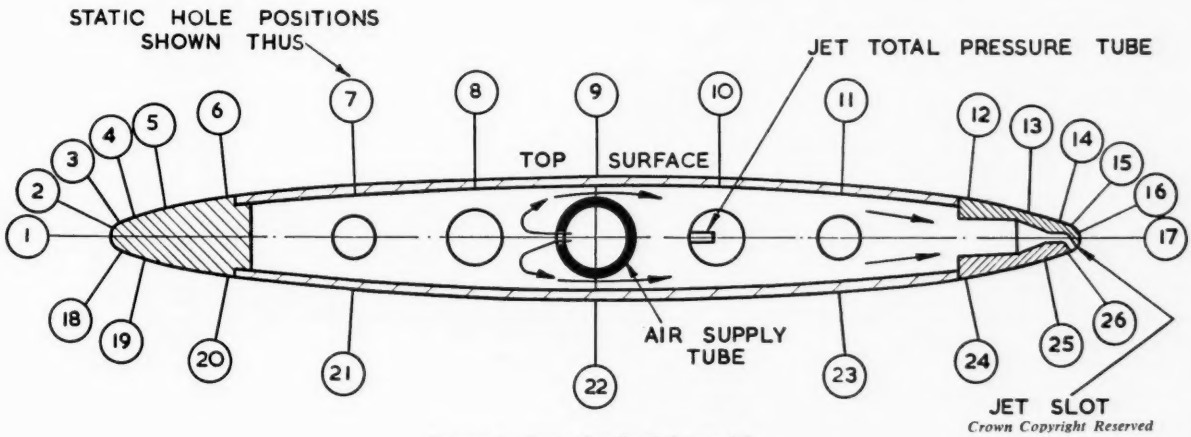

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FIGURE 6. Some details of the models.

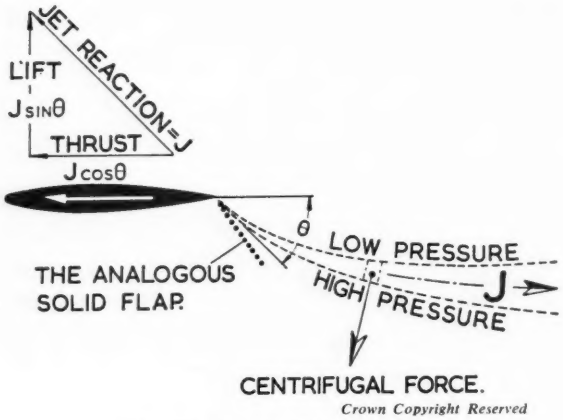

FIGURE 7. The basic principle.

aerodynamic or pressure component and a jet or reaction component, but rather to think in terms of the whole. The results for the 58·1° jet angle are quite typical, and Fig. 9 shows for that model the variation with C_J, the jet coefficient, of C_{L_0}, the total lift coefficient at zero incidence. From this diagram it will be seen that even the pressure or aerodynamic lift component is greater than could be generated by any other practical mechanism, while, beside the total, the idea of using only pure jet lift looks decidedly uneconomic. This last point is perhaps better illustrated by Fig. 10 in which the lift gain, G, is a direct measure of the total lift which can be generated per pound of available jet reaction. Thus, for many practical purposes the jet flap can be regarded simply as a jet lift amplifier of which the gain lies generally between three and thirty.

In the present theory an empirical factor is involved in the estimation of the lift at zero incidence, so it would not be fair to attempt a comparison with experiment. The lift slope, on the other hand, is almost independent of that factor and so, in Fig. 11, a comparison is made between the measured values and the theoretical curve for an undeflected jet on a thin aerofoil.

For various reasons the conventional $C_M - C_L$ curve is not a good way of showing up the pitching behaviour of a jet flapped aerofoil, so in Fig. 12 an alternative presentation is adopted. In this diagram, which includes all the reaction effects, the total lift coefficient is plotted against the positions of the aerodynamic centre and the centre of total lift. Roughly speaking, the aerodynamic centre is at the quarter chord point and the centre of lift is at mid-chord, but for a given thrust they both move gradually aft as the air speed is reduced. Fundamentally, of course, C_J and not C_L is the basic variable, and in Fig. 13 it will be seen that on this basis these two lift centres agree fairly well for all three jet angles.

1.3. STALLING BEHAVIOUR

Whereas with a conventional aeroplane its incidence provides the one and only significant control derivative,

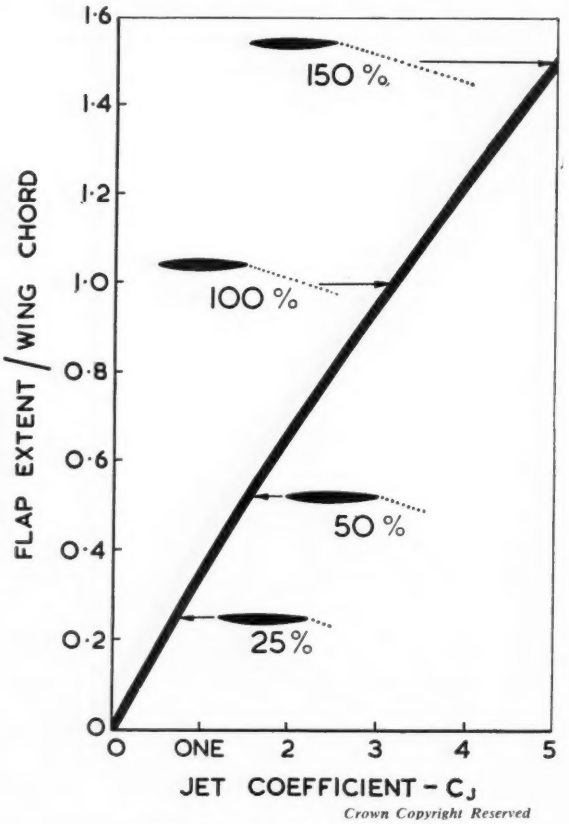

FIGURE 8. The analogous flap size.

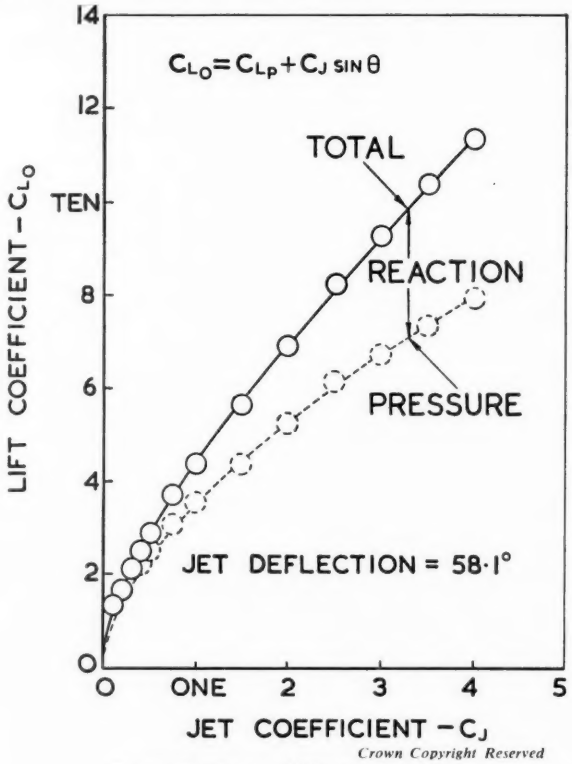

FIGURE 9. Measured lift at zero incidence.

$(\partial C_L)/(\partial \alpha)$, the lift on a jet flapped wing can be substantially altered at any incidence by changing either the jet angle, θ, or the jet coefficient, C_J. Hence, in discussing stability it would seem necessary to consider all three derivatives—$(\partial C_L)/(\partial \alpha)$, $(\partial C_L)/(\partial \theta)$ and $(\partial C_L)/(\partial C_J)$. In practice, the situation is much simplified because, under high lift conditions, large variations in the jet angle can produce rather unpleasant effects—certainly bad handling characteristics and possibly a catastrophic stall—so that $(\partial C_L)/(\partial \theta)$ can conveniently be forgotten.

The second simplification is that it is manifestly impossible to stall a jet flapped wing by increasing its thrust; C_L will go on increasing *ad infinitum* whatever the physical appearance of the flow. This is evident from Fig. 14, which covers the same range of C_J as do the previous figures. Not only C_L, but also all the other overall aerodynamic properties go on smoothly with C_J, despite what amount latterly to a full-chord separation bubble. From Fig. 15—a transcription of the last of these photographs—the reason can be seen to be the tremendous influence of the jet mixing entrainment effect. For example, from the undersurface flow it will be noticed that the main stream is actually turned to meet the jet, and the extensive nature of this inflow produces a rather interesting result. As the thrust is increased the stagnation point moves steadily aft, but at very high lift it eventually stops and then moves forward again.

That this entrainment process is also the key to the incidence stalling behaviour is suggested in Fig. 16, which depicts for the purposes of illustration a much simplified view of the real situation. In this view the

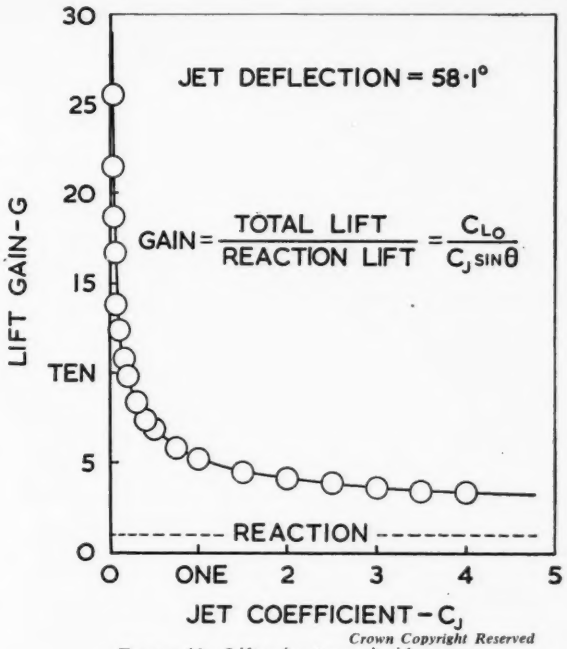

FIGURE 10. Lift gain at zero incidence.

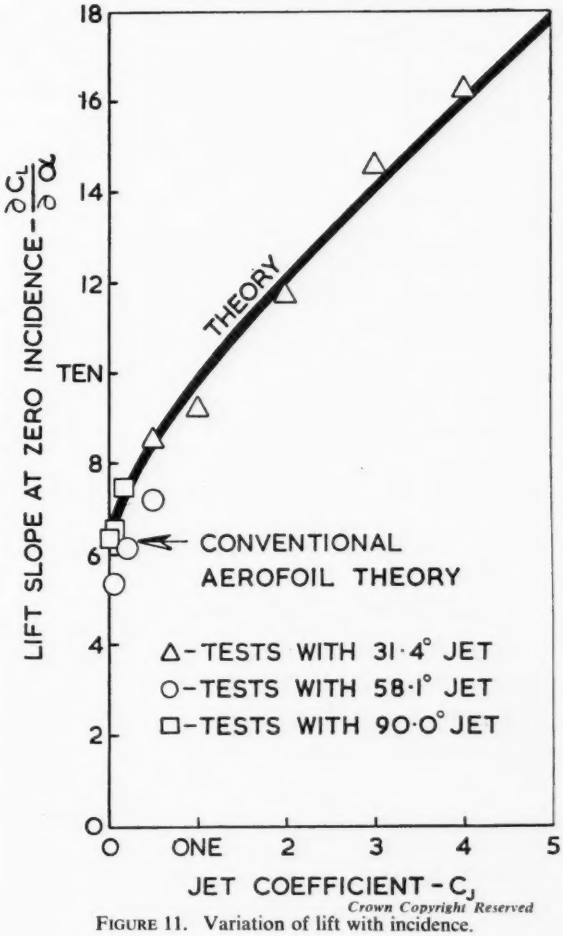
LIFT SLOPE AT ZERO INCIDENCE - $\frac{\partial C_L}{\partial \alpha}$
THEORY
CONVENTIONAL AEROFOIL THEORY
△ - TESTS WITH 31·4° JET
○ - TESTS WITH 58·1° JET
□ - TESTS WITH 90·0° JET
TEN
ONE
JET COEFFICIENT - C_J
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FIGURE 11. Variation of lift with incidence.

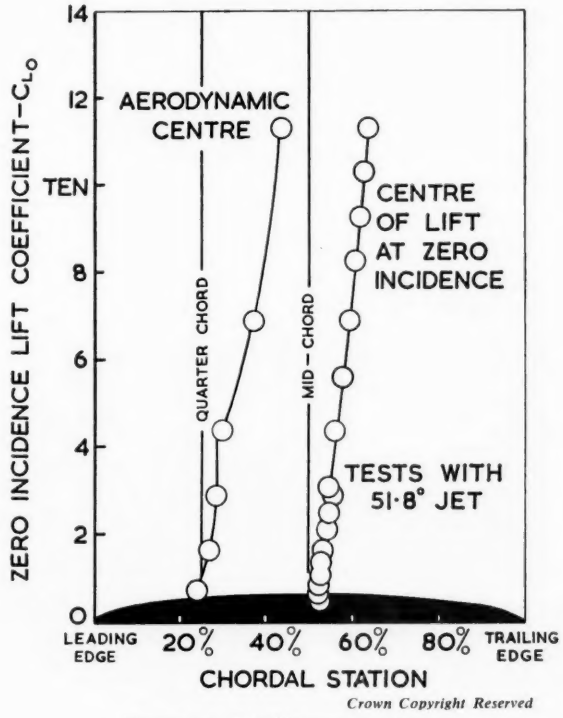

FIGURE 12. The lift centre positions.

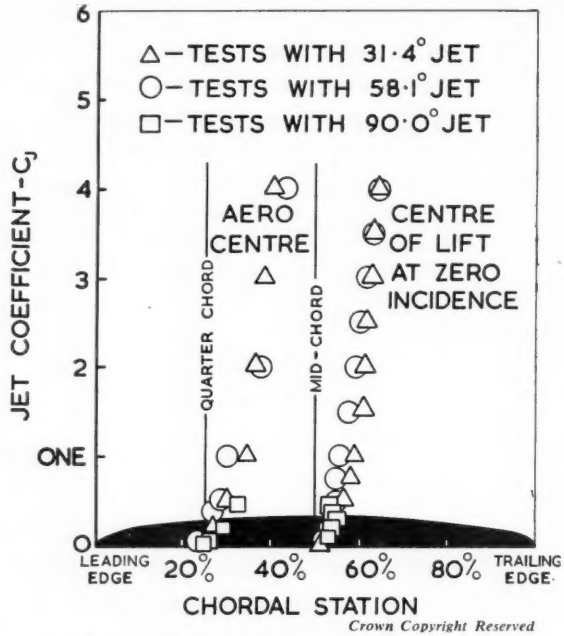

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FIGURE 13. Correlation with the jet coefficient.

entrainment effect is thought of as having a discrete sphere of influence. As the incidence is raised the separated main stream is eventually thrown clear of this sphere, so that the bubble bursts to form an open wake; and this means a stall, that is, a reversal in the sign of the lift slope, $(\partial C_L)/(\partial \alpha)$. Naturally, the greater is C_J the bigger is the sphere of influence, and this effect has two main results.

(*i*) As C_J is raised the danger of an incidence stall is reduced at any given value of C_L.

(*ii*) If two aerofoils be compared at the same zero incidence lift, but with differing jet angles, the one with the larger angle will naturally have the smaller C_J value and hence will be more prone to an incidence stall.

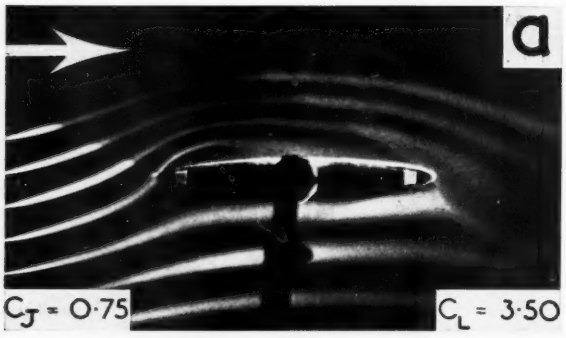
The experimental lift curves for the 31·4° model are shown in Fig. 17, in which the stalling envelope appears to asymptote to the vertical at about +4° incidence. Indeed, at a C_J value of 4·0 there is a suggestion of complete installability, but this should be treated with suspicion. In general, the lift curves do not curl over below +3° and, when it does occur, the severity of the stall increases with C_J. The envelopes for all three models are shown in Fig. 18, from which it will be seen that, even with large jet angles, there exists in principle the possibility of producing an unstallable aircraft, for the lift can be raised indefinitely without crossing the envelope.

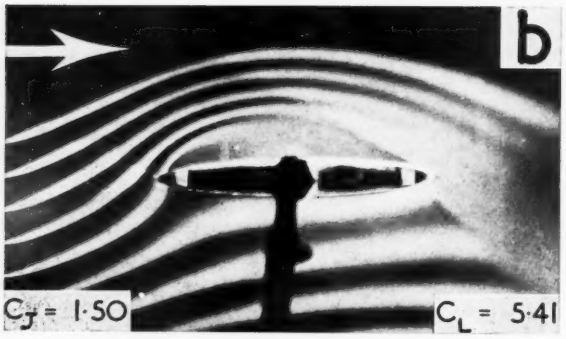
The full results for the 58·1° model are shown in Fig. 19, where the lines will be seen to curve long before the stall. This is undoubtedly due in part to the greater volume of the separation bubble, but it is thought also to be connected with a substantial increase in the jet mixing losses—a point which is discussed later.

1.4. INTERFERENCE EFFECTS

The interference effects on a jet flapped aerofoil are apparently different from those in a conventional system for, as is shown in Fig. 20, a substantial part of the lift producing "structure," namely the jet itself, is grossly distorted by the presence of an adjacent ground. With the wing in motion the jet entrainment effect draws through the clearance space an appreciable ventilating flow—presumably a useful practical attribute.

Aerodynamically, the effects of this jet distortion are fortunate, for they result in the loss of lift being only a small fraction of what it would be with any other lifting system. In the take-off and landing of an aircraft the effect will not, of course, be negligible and, in Fig. 21, it is illustrated for the 58·1° model at ground clearances of one chord and less.





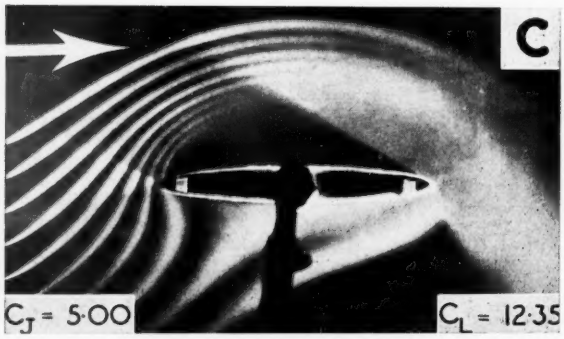


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FIGURE 14. Growth of the separation bubble.

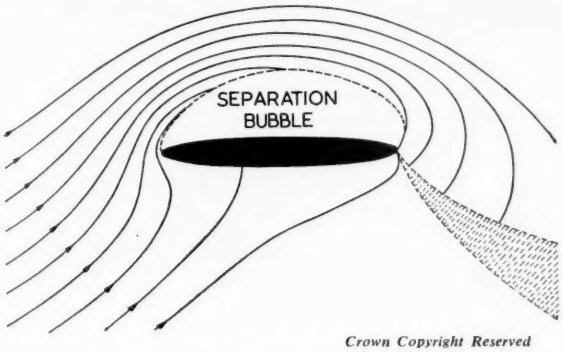

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FIGURE 15. A transcription of Fig. 14c.

2. The Thrust of a Two-Dimensional Wing

2.1. THRUST AND DRAG

Suppose for the moment that the jet fluid is not permitted to mix with the main stream. Since the basic lifting mechanism is in no way affected by this change, the jet will continue to carry out of the system a horizontal momentum flux of J pounds. Hence, following Newton, the aerofoil must somehow or other experience an equal and opposite total thrust of J pounds, so that we have as a starting point the theorem that,

In an idealised two-dimensional jet flap system the gross thrust is equal to the total jet reaction and independent of the angle of deflection of the jet.

There are several ways of looking at this situation, but they all lead to the same surprising result which, while appearing all very neat in theory, seems far too good to have any practical meaning. But it has; for in quite crude experiments with obvious and appalling losses, a jet angle of 90° and therefore no reaction thrust can easily be persuaded to yield a pressure thrust of from 0·3 to 0·4J. One such example is that of Fig. 22 in which the proximate cause can be seen to be the substantial low pressure region on the nose of the aerofoil.

Partly because it encourages one to strive for the last possible ounce of pressure thrust, but also for more prosaic reasons, the thrust of an aircraft is therefore taken to be the full value, J, of its engine thrust whatever

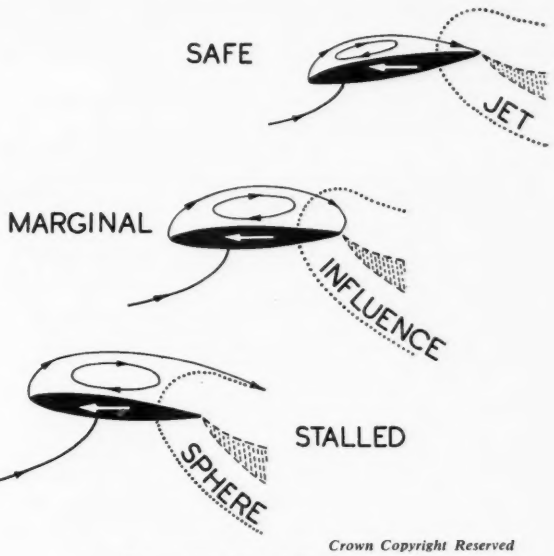

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FIGURE 16. The stalling process.

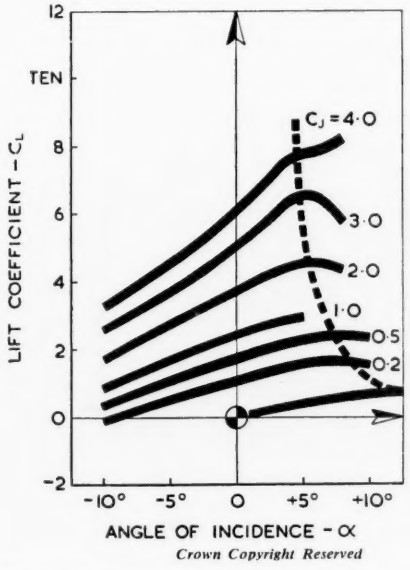

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FIGURE 17. Stalling behaviour of 31·4° model.

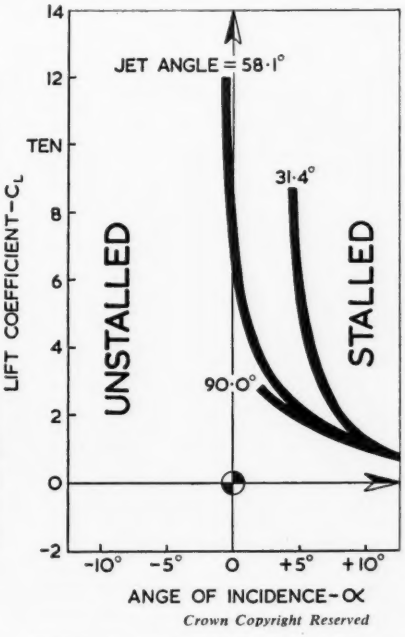

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FIGURE 18. The three stalling envelopes.

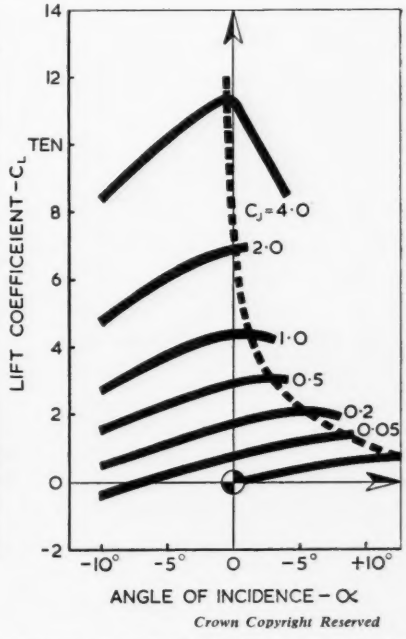

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FIGURE 19. Stalling behaviour of 58·1° model.

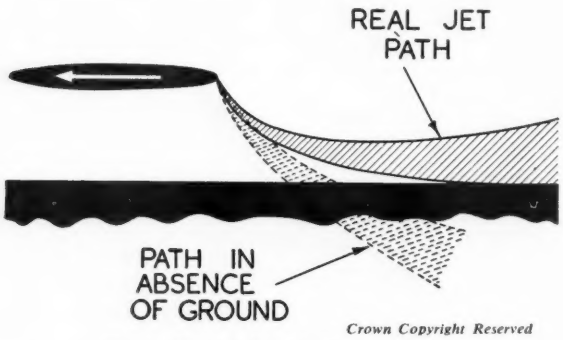

FIGURE 20. Jet distortion by the ground.

the jet angle may be. Since the apparent losses are due to the jet mixing process they can then fairly be described as jet drag and given, in coefficient form, the symbol C_{DJ}.

Again there are several ways of looking at the jet drag mechanism, but of these the simplest is perhaps that of Fig. 23 in which the aerofoil is at rest. In the entrainment process the surrounding air is accelerated locally in the vicinity of the trailing edge, so producing a suction drag on the profile. In flight there is of course a similar effect, but the rate of entrainment and hence the drag then depends upon the jet velocity relative to the main stream: that is, it depends upon the rate of shear between the two fluids.

Some rough exploratory experiments were made with an undeflected jet issuing from the model of Fig. 24, which aerofoil suffered on account of its simple construction from a wandering transition point. Thus, under nominally identical test conditions, a number of quite different drag curves was obtained (*see* Fig. 25). The jet drag is given of course by the slope of these curves and, to make quite certain that there was no mistake, one test was made with a large leading edge spoiler fitted, as shown. The result is quite conclusive and it suggests that in cruising flight an aircraft with a cold propulsive jet must be expected to suffer from a jet drag which is equal in magnitude to some five or six per cent. of the gross thrust.

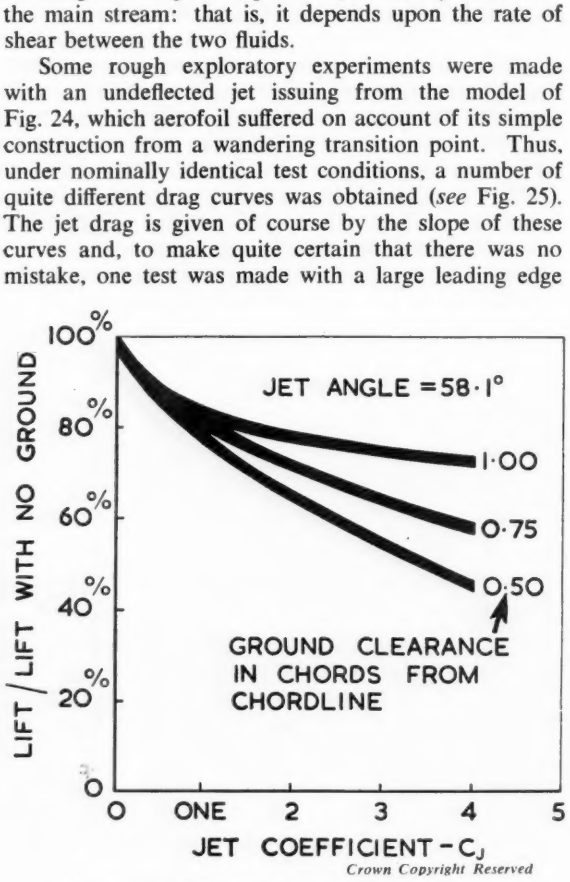

FIGURE 21. The ground effect at zero incidence.

2.2. CRUISING FLIGHT

Since it is desirable in practice to use the same exhaust system at all times this last conclusion appears rather ominous, but fortunately there is one important variable which has yet to be taken into account—the density of the jet gas.

It has just been shown that when the jet and main stream densities are the same there is, in practice, an entrainment or a sink effect, while in classical aerodynamics the growing boundary layer or wake of an aerofoil can be simulated by a source effect. Hence, in such a system, the existence of sinks or sources, of a pressure drag or a pressure thrust, seems to depend upon whether the jet or wake velocity is greater or smaller than that of the main stream. In a penetrating and markedly heuristic analysis, Stratford[11] has shown that the real criterion is that of Fig. 26; that is, that the significant variable is not the relationship of the two velocities, but is the ratio of the density-velocity product, $\rho_J V_J$, to that of the main stream. When $\rho_J V_J > \rho_0 V_0$ there is jet drag; when it is smaller there is an analogous thrust and, as it happens, the value of $\rho_J V_J$ in cruising flight will approximate closely to $\rho_0 V_0$ for most practical aircraft, whether they be propelled by simple jet, by-pass or ducted fan engines.

In a confirmatory experiment the model of Fig. 24 was run with a pure hydrogen jet of which the thrust was progressively raised to give the result of Fig. 27. From the drag scale it will be seen that this experiment involved the measurement of very small differences, so on that account alone an accuracy of better than, say, ± 10 per cent. could not have been hoped for. On top of this difficulty, the hydrogen was expanded from a reservoir at up to 3,000 lb./in.^{2} so that, because of cooling effects, there could be no guarantee that the model

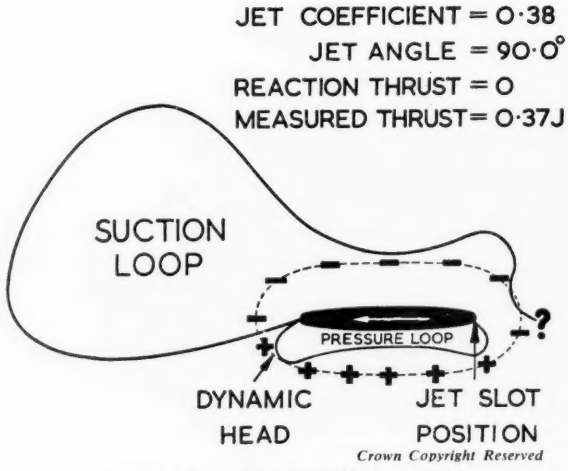

FIGURE 22. The pressure induced thrust.

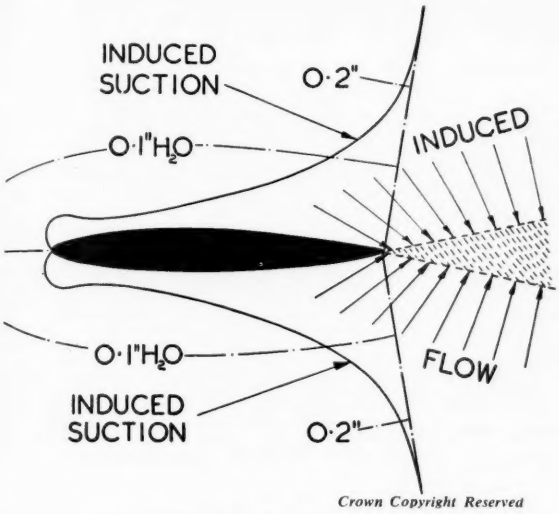

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FIGURE 23. The jet drag on an aerofoil at rest.

slot width was invariant with time. Nevertheless, by repeating the results under a number of slightly different conditions, sufficient evidence was accumulated to show that there was undoubtedly a region of low thrust in which the jet drag was negative, as illustrated.

2.3. AT TAKE-OFF AND LANDING

Now the magnitude of the jet drag has just been shown to depend upon the strength of the entrainment effect and so upon the shear velocity between the jet and the main stream fluids. As this shear velocity increases, so will the loss. Previously, it was seen that with large C_J values the lower main stream does not even run straight into the jet but, near the nozzle, is turned to meet it head on. The violence of this initial mixing is thought to be one of the main sources of jet drag under high lift conditions and is why C_{DJ} must be expected to increase rapidly with the jet deflection angle.

Since the jet drag must appear also as a loss of momentum flux in the mixed stream, there arises naturally the question of how this flux loss will affect the

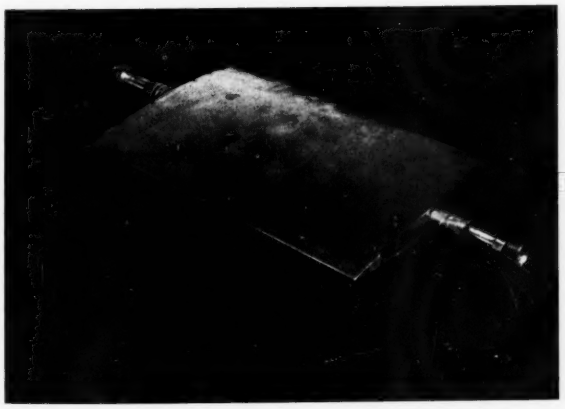

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FIGURE 24. The 8-inch jet drag model.

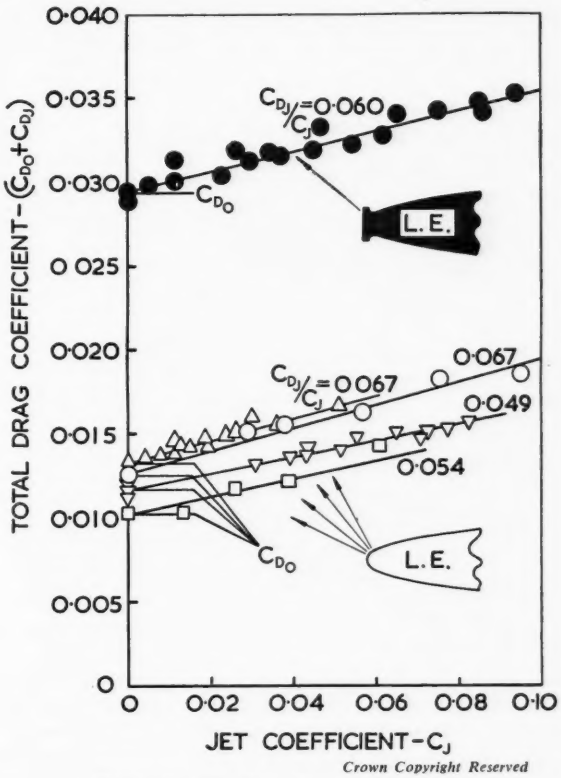

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FIGURE 25. The drag of an undeflected jet.

total lift on the system. On this point there is no direct evidence, but intuition suggests that a lift loss can be produced only by that mixing which occurs in the highly curved region of the jet before it turns parallel to the flight path. Thus even a large jet drag might correspond only to a moderate loss of lift and, in fact, this is borne out by the lift-incidence curves for the 58·1° model.

If two given elements of the jet and main stream are to be mixed with the minimum possible loss, the process must clearly be conducted as gently as possible. To take one absurd but illuminating example; were the

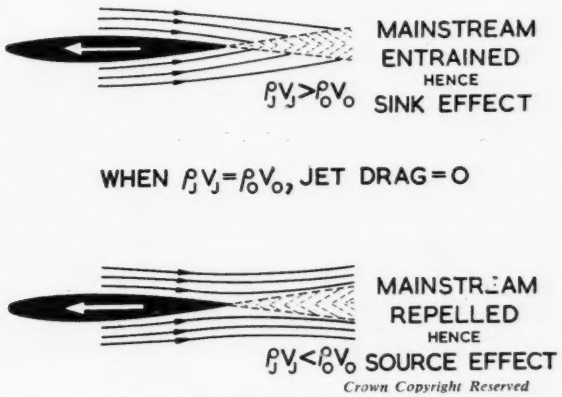

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FIGURE 26. The effect of jet density.

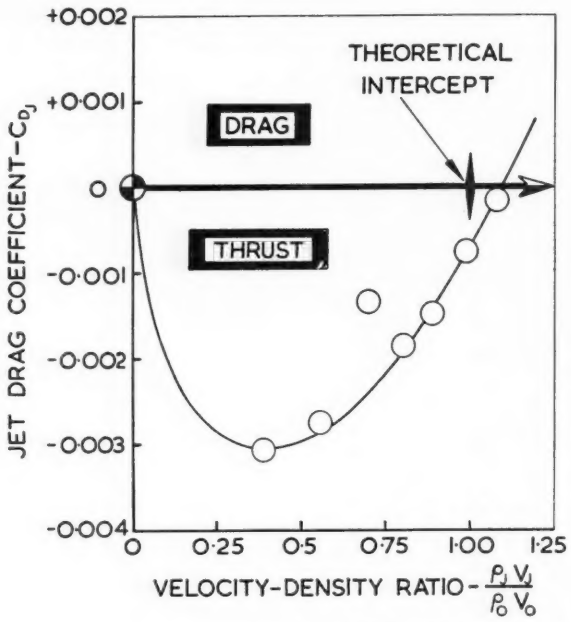

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FIGURE 27. The hydrogen test results.

streams to be mixed entirely in a very low pressure region of the field, the absolute velocities of both would be high, but, following Bernoulli, their mutual shear velocity would be negligible. Hence, the mixing could be effected without loss by a spoon travelling with the flow. This is merely another way of looking at the fact that the aerofoil, jet and main stream can be considered respectively as the structure, primary and secondary fluids of an introverted thrust augmentor or ejector. Hence by good design, the system can be made to yield in principle a thrust gain, so that the total thrust on the aerofoil is greater, not smaller, than J. Once more there are several ways of looking at the process and all of them give this same surprising result.

For this augmentation process to be possible a large region of low pressure is clearly necessary, and this means high lift; so the inevitable experimental check was attempted on the model of Fig. 28. The jet cross-sectional area was about the same as that of the other models, but instead of a slot the fluid issued from a large number of fish-tail nozzles between which the main stream was drawn by the mixing process. To produce the lift, the mixed jet then flowed over a short 45° flap at the shoulder of which a small and apparently unnecessary boundary layer control sub-jet was incorporated by way of an insurance premium.

Unfortunately the result was neither positive nor negative, but tantalisingly inconclusive. Observation showed that the flow was behaving more or less as expected, but despite this a thrust loss of 17 per cent. was recorded. That this did not constitute a negative result was due to the obvious existence of substantial induced drag, while several other possible sources of loss also were discovered. Hence, a successful experiment would have called for a redesign not only of the model, but also of the whole working section and thrust balance.

3. Wings of Finite Span

About jet flapped wings of finite aspect ratio very little is known although, ironically enough, the only available results are those obtained before the Second

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FIGURE 28. The 8-inch thrust boost model.

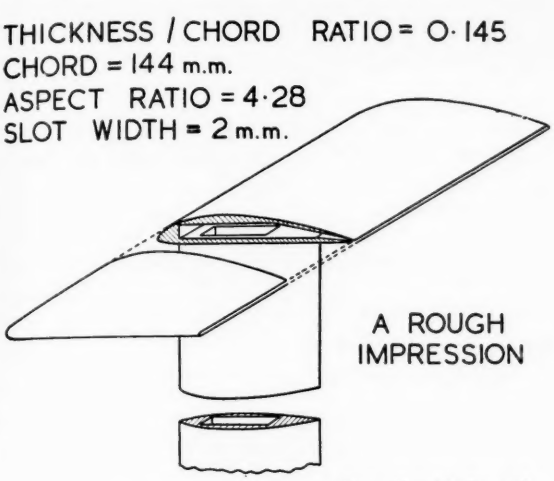

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FIGURE 29. The first jet flapped aerofoil.

World War by Hagedorn and Ruden[4] with the model illustrated in Fig. 29. The results are shown in Fig. 30 and, not only is this believed to be the first jet flap experiment ever conducted, but the authors correctly diagnosed the active principle in the following words*:—

> ". . . , with blowing there will be a pressure difference at the trailing edge—unlike the case with zero jet speed. The pressure difference across the jet stream probably decays only gradually in the downstream direction and this is the force responsible for curving that stream until it is parallel to the undisturbed main stream. The pressure distribution on the aerofoil consequently becomes more rectangular and the lift therefore increases."

However, since the tests were done only during the calibration of a model intended for work on boundary layer control and, presumably, since jet propulsion was then a thing of the future, those early results were never followed up. Nor was there reported any thrust-drag information, pressure plotting, or flow study.

Although the reaction lift of a real jet flapped wing cannot be affected by its three-dimensional nature, the total rather than the pressure lift must be the cause of the induced incidence, for even the reaction lift is felt by the main stream in the form of a pressure difference across the jet sheet. Hence, very nearly but not quite, the conventional formulae will be used in correcting the pressure lift for the effects of aspect ratio. Physically, however, the flow is likely to be different in one important respect, and this is illustrated roughly in Fig. 31, which is intended to represent a view looking upstream towards the trailing edge of a wing. If it be imagined

*". . ., aber auch darauf, das an Hinterkante noch kein Druckausgleich vorhanden ist (wie bei $va/v=0$). Der Drucksprung setzt sich wahrscheinlich langs der Ausblaseschicht in das Strömungsfeld fort und wird zur Umlenkung dieser Schicht bis in Anblasrichtung verwendet. Die Druckverteilung am Tragflügel wird dadurch völliger und der Auftrieb grösser."

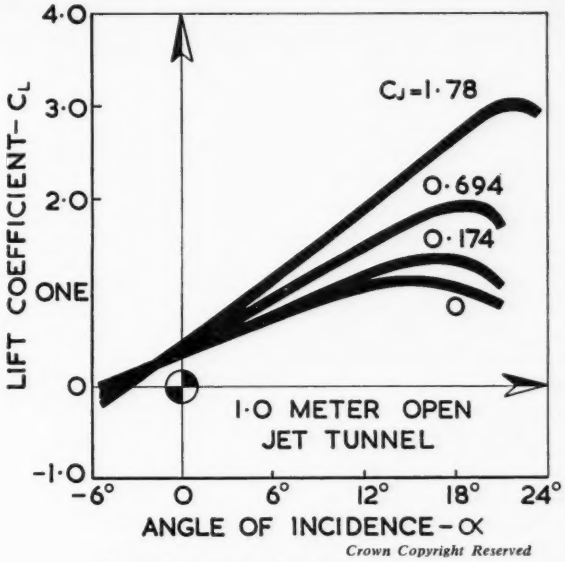

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FIGURE 30. The first experimental results.

for simplicity that the wing sheds a conventional tip vortex, this will be partly, if not completely, entrained by the jet, to which it must impart its angular momentum. Hence, since at high C_J values the jet will be moving very much faster than the main stream, the result will be a reduction in the magnitude of the usual induced negative incidence.

In practice, of course, the shed vorticity will go more or less directly into the jet, so that it will never really appear as a tip vortex and an alternative view is perhaps the best. This is that all real wings generate their lift by throwing down the main stream, so that, if through its entrainment action a jet flapped wing can get to grips with more than the usual mass flow, it must throw it down at less than the usual angle. With its relationship to the Froude efficiency of propulsion, this argument suggests also why the induced drag of a jet flapped wing will be appreciably less than that of a conventional wing with the same conditions of loading. Just how much less it is not yet possible to say.

PART II

Some Aeronautical Considerations

Before the jet flap principle can be applied properly much of the theory and practice of low speed flight must be written anew for, aerodynamically speaking, the situation is akin to that which prevailed in or about the year 1900. With technology as it now stands this may not of course take long but, for the present, it would be foolish to attempt any prediction concerning the aircraft types which will emerge. So far, the horizon is just nowhere in sight.

Nevertheless, in pursuing the opening theme it remains to be shown that a practicable aircraft can be constructed around the principle, and for this exercise some sort of model is clearly necessary. Thus, although

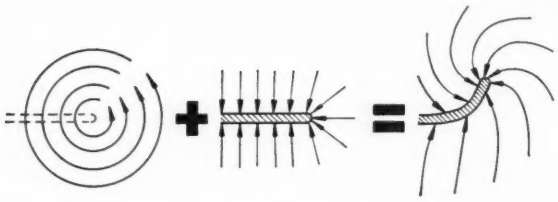

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FIGURE 31. The three-dimensional story.

sketched as realistically as circumstances will allow, I can only hope that this example will be accepted as a first, simple expedient.

1. Introduction

1.1. THE *de novo* APPROACH

The analogous flap size for a typical aircraft of, say, the Comet calibre is illustrated in Fig. 32, which suggests that in cruising flight the machine could be regarded simply as a conventional aeroplane. In low speed flight the situation is not so obvious for, although there is now a rough working knowledge of the properties of a jet flapped wing, little has been deduced about the likely behaviour of a whole aircraft. One thing, however, is certain—that in flight through still air the maximum C_L value will be determined solely by the available thrust, and that it will be very large indeed.

For example, in landing trim this machine might display a wing loading of 55 lb./ft.^{2} and, with fully developed by-pass engines, a jet reaction to aircraft weight ratio of about 0·55. With no contingency allowance and with a jet angle of some 40° even this quasi-conventional aircraft would be off the present experimental map, but a slight extrapolation suggests for it an approach speed of 35 knots at a total lift coefficient of about 13½. The low speed problem is thus mainly that of so designing the machine that, with all due allowances for engine failure, gusts, baulking and human error, and so on, the ideal, still-air performance can be approached as closely as possible. That is, of course, the common problem of all high lift aircraft, but with the jet flap there exist two novel and potentially powerful possibilities.

(*i*) There is in principle a chance of making the aircraft unstallable.

(*ii*) Due to the inherent lift-thrust coupling, it should be possible to control far below the minimum drag speed.

However, in striving for these characteristics it is found that not only the lift but also all its controlling increments must be generated aft of the effective mid-chord point, and this suggests that the conventional elevator system be abandoned. So far as the pilot is concerned there could be a perfectly conventional cockpit layout and the rudder would follow normal practice, but the tailplane would be fixed, while the jet flap would assume the functions of the elevators, ailerons, flaps and air brakes.

In practice the flap control might lower the jet through some 30 to 40 degrees, while at the same time trimming the one-piece tailplane to an appropriate downwash angle. On top of this, the control column would provide at all times a vernier action of plus and minus a few degrees, the jets on either side of the fuselage acting together as elevators and differentially as ailerons. Finally, the jet would be divided into a number of contiguous spanwise sections, adjacent elements moving differentially about any common datum for the purpose of generating induced drag independently of the overall lift.

1.2. THE SHROUDED JET

In practice this scheme entails with a pure or simple jet flap two quite unacceptable snags—the responsibility for the aircraft control system must be handed at once to its engine designer, while the very survival of the craft clearly depends upon the unfailing operation of its power plant. These difficulties can be overcome by the introduction of a small hinged flap or jet shroud as illustrated in Fig. 33. The term shroud arose because the arrangement was originally conceived only for the control of the jet and the reduction of its entrainment drag; but since then, the appendage has been found to offer so many engineering advantages that its atrophy now seems unthinkable.

In operation the jet follows the shroud by what is commonly termed the Coanda effect[12] and, with a little care, there is no difficulty in turning any sort of jet through 90° and more. The best shroud size will vary from one design to another, for it depends upon many diverse factors; but typical values might lie in the

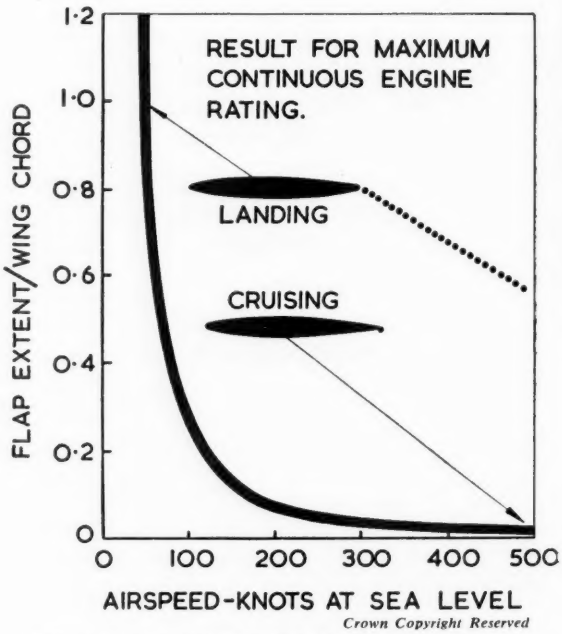

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FIGURE 32. The analogous flap size for a typical air liner.

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FIGURE 33. A practical embodiment of the principle.

range from three to ten per cent. of the wing chord, with a bias towards the lower figure.

Since the lift from a small flap varies as the square root of its chordal extent, the effects of the shroud and jet will clearly not be additive. One approximate theoretical result is displayed in Fig. 34 which suggests, for example, that while the separate C_L values from a five per cent. shroud and a jet of C_J value 1·0 may be respectively 1·8 and 5·4, they will yield in combination only 6·1. Thus, while the shroud will be all-important in cruising flight, it can, with perhaps one exception, be neglected in first order high lift calculations. The exception is its effect on the centre of total lift, and this could be important because it makes possible a reduction of the unusually large tailplane volume coefficient.

1.3. STATIC STABILITY AND CONTROL

This large tail volume may prove embarrassing, since it implies, of course, extra drag and structure weight. The difficulty arises because, as in Fig. 35, the aircraft centre of gravity will be in the vicinity of its mid-chord point, so that the distance between the aerodynamic centre of the wing and that of the whole aircraft—that is, the neutral point—must have about twice its conventional value.

In high speed flight the equivalent of elevator control will be a movement of the shroud, so that the controlling lift increment will be generated close to the mid-chord point and the response will be a ballooning of the aircraft with the tailplane serving purely as a weathercock to pitch it into the resulting climb.

In low speed flight with a high aspect ratio and the tailplane properly trimmed, the balance of forces should be as in Fig. 36. Its centre of lift having moved aft, the wing will exhibit at zero incidence a large nose-down pitching moment about the centre of gravity. This will be balanced partly by the upwash and downwash couple on the fuselage and partly by under-trimming the tailplane, but also by the whole machine adopting automatically a nose-down equilibrium attitude. With sufficient of this third ingredient it is clear that the more lift the pilot applies the farther does the craft move from its stalling incidence—hence the possibility of an unstallable aircraft.

2. Some Three-Dimensional Effects

Since the jet flapped aerofoil is so insensitive to upper surface separation effects it may well prove a cure for many of those vices which are commonly associated with sweepback. Hence, in a first look at the three-dimensional picture, we can safely afford to omit plan form in favour of aspect ratio.

Two-dimensionally, it has been suggested that the aircraft should be designed to adopt in low speed flight a small negative incidence. In practice the argument remains, but the nose-down attitude will be struck relative to the downwardly induced main stream rather than to the flight path. Hence, while the static stability of the machine will be unimpaired, its attitude relative to the flight path will be one of such a positive incidence that, to a first order, the two-dimensional lift and centre of lift will be obtained independently of the aspect ratio.

In the last analysis, the crucial requirement for good low speed handling is that, without throttle adjustment, an increase in C_L should produce a sustained increase in the angle of climb. For any machine controlled by elevator movement this condition defines the minimum drag speed, but for a jet flapped wing controlled through its throttles the handling limit is very much lower; indeed, it is well below the speed at which level flight is possible.

The reason can be seen in Fig. 37, which depicts the relative lift, jet and drag coefficients for a typical landing approach. Since the machine would land in a fully streamlined condition, its profile and parasitic drags will be so small that, in a first analysis, they can be balanced against the rate of descent and forgotten. Thus, while the thrust will be equal to the sum of the induced and jet drags, these three all increase directly with C_L^2, so that any throttle adjustment will vary the lift without disturbing the thrust-drag balance.

Hence, in practice the pilot can use his throttles as a rate of descent control which produces no first order change in the air speed or attitude of the craft.

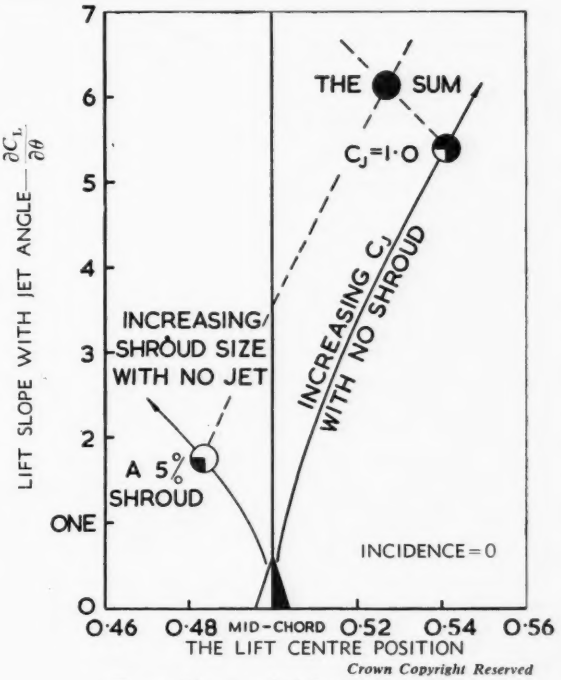

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FIGURE 34. A typical theoretical result.

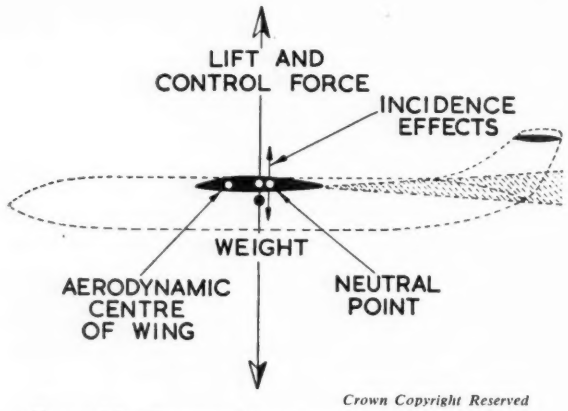

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FIGURE 35. The general arrangement for control without incidence.

3. Some Factors Affecting the Maximum Lift

Since the two-dimensional experiments have disclosed significant ground interference effects, it might reasonably be supposed that, during the take-off and landing, these would cause some embarrassment. No assessment is yet possible, but observation suggests that the effects are of the same order as, but in the opposite sense from, those which normally occur due to the suppression of three-dimensional effects, so that in the long run the overall disturbance may prove trifling.

3.1. GUSTS

While little enough is known about the sort of gusts which will be encountered, virtually no information is available concerning the likely dynamic response of a jet flapped aircraft. The one established fact is that the lift on a jet flapped wing varies not as the square of, but directly as, its flight speed. Hence, for given loading conditions, a horizontal gust will have much less effect than it would on a conventional machine.

Were one wing to drop in a gust, a natural reaction would involve the application of opposite aileron, which produces a differential movement of the jets on either side of the fuselage. Thus, both the induced and jet drags would increase on the dropped wing while decreasing on the other so that, as the machine regained an even keel, it would turn markedly off course.

With all engines intact in still air such an incident could not of course arise, for any required lateral or directional correction would be made as a slow, fully co-ordinated manoeuvre. Thus it is evident that one way in which atmospheric turbulence might limit the maximum lift is through the creation of lateral handling difficulties which are analogous to those that occur with a conventional aircraft well below its minimum drag speed.

The probable stability effects are at first sight more serious, for although the pilot cannot stall the aircraft, the encounter during a 40 knot approach of even a moderate upgust must be presumed to cause trouble. However, the situation is by no means as bad as it looks at first sight for, apart from two obvious evasive design measures, the stall may itself transpire to be relatively innocuous.

The first measure is applicable only to highly powered aircraft of moderate aspect ratio on which the three-dimensionally induced negative incidence might be twenty degrees or more. With plenty of thrust in hand, it could pay to accept, say, ten degrees of this to yield on the one hand a reasonable landing attitude and on the other an inherent anti-gust margin.

On a high speed aircraft the aspirated air velocity may be some 700 or 800 ft./sec., and this suggests the second measure for, in low speed flight, it would correspond to an extremely high suction in the intake plane. Thus the intake system could comprise a continuous, full span, leading edge slot, such that the stalling incidence of the wing is substantially increased.

Superficially, this arrangement closely resembles a well known system of leading edge boundary layer control, but the likeness is misleading; for one thing, the aspirated flow is vastly greater than that in the boundary layer. This arrangement might indeed prove a logical and important move in the aerodynamic synthesis of the aircraft for, since the small intake width could lend itself to the installation of an unusually efficient diffuser followed by low duct velocities, there need be little or no resulting intake loss penalty.

However, not all aircraft can have buried engines; the majority are and always will be propeller-driven, and for these the jet flap principle will be no less important than for their better integrated brethren. Naturally, there is always the possibility of conventional leading edge boundary layer control; but also there is a more economic alternative. When the long upper surface bubble finally bursts to form an open wake the lift loss must clearly be confined to its induced component, which acts well forward of the aircraft centre of gravity. Thus, even with a two-dimensional aerofoil it is to be expected that the stall will be accompanied by a substantial restoring moment, and such a result is quite evident in the curves of Fig. 38. With a complete

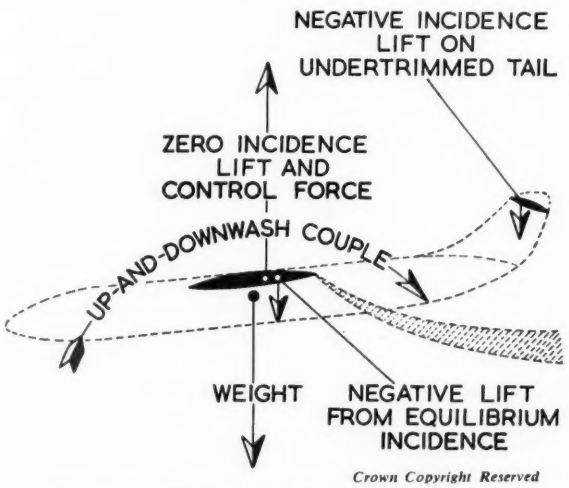

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FIGURE 36. The balance of forces in low speed flight.

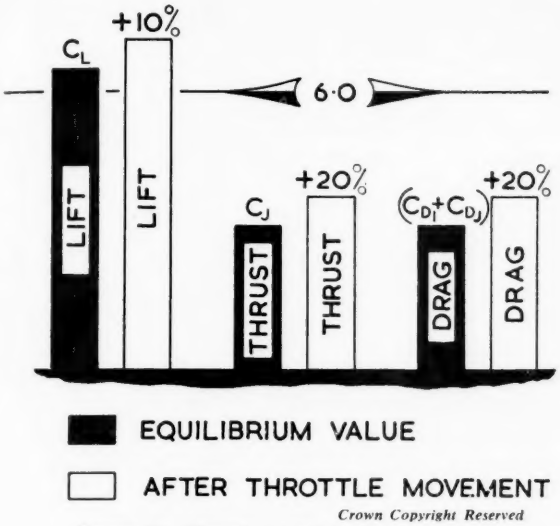

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FIGURE 37. Throttle control on the approach.

aircraft the effect will be even more pronounced due to the loss of downwash on the rear fuselage and tailplane, so that in practice the stall may well constitute a handling problem rather than a hazard.

Although the aircraft may thus take care of itself in pitch there remains the difficulty of the dropped wing. At this point major dynamic effects must be presumed to cloud the picture, but there can be little doubt that, in the presence of an ample thrust reserve, safety can be guaranteed at the expense of spoiling the approach. However, to keep things in perspective, it should be remembered that the object of the exercise is not to line up with a runway at, say ,120 knots, but to drop into a cabbage patch at forty or less.

3.2. ENGINE FAILURE

As with gust behaviour, the precise allowances which must be made to guard against engine failure cannot yet be assessed, and may emerge only after much flying experience has been accumulated. However, since this contingency is even more amenable to design treatment, it is well worth looking at a few cardinal principles, the first question being what happens when the fuel runs out?

In modern practice the forced landing is commonly to be dreaded, but with the sort of speeds now under consideration and an all-up weight of 100,000 lb. or so, there is clearly every hope of a safe descent even in a mountainous or well populated terrain. Thus, it would be illogical not to carry in an emergency system the five minutes fuel which would be required for air-braking and crash landing purposes after a long, unpowered glide from altitude.

In the more likely event of an engine cut during take-off or landing, there are two main points to be watched. The first is that the most embarrassing consequence will be neither the loss of thrust nor the loss of lift, but rather the yawing and rolling moments which must be checked immediately after the incident. The second is that there is no fundamental difficulty, but only an economic one; for the necessary thrust margin will depend primarily on the number of engines employed and the skill of the designer.

In returning once more to the example, its wing layout might follow the scheme of Fig. 39. Basically, there are eight identical engines each powering one-eighth of the wing area, and all of these, being by-pass units, would be required for the cruise. Although they are shown as four-cylinder units, this has nothing to do with the problem of engine failure, but is simply for ease in packing.

Ideally, the exhausts would be pooled entirely or in groups, but for several obvious reasons this temptation must be resisted. Although it is reasonable to insist that the control system shall cope with a failure of any one of the six inboard engines, it cannot be expected to handle a single outboard failure. Hence, the outermost engines would have cross-coupled fuel systems—rather like a Ward-Leonard set—so that whatever happened they would run down together.

Now this powered wing incorporates two essential aerodynamic ingredients—the jet flap itself and the fully integrated, anti-gust intake. While the former may be allowed to fail the latter cannot, and so part of the wing must be used as a transfer duct which connects each engine through its non-return intake valve to the common intake slot. Structurally, very little of this cold, low pressure ducting need be parasitic and, as illustrated, it would transport the air at little over 200 ft./sec.

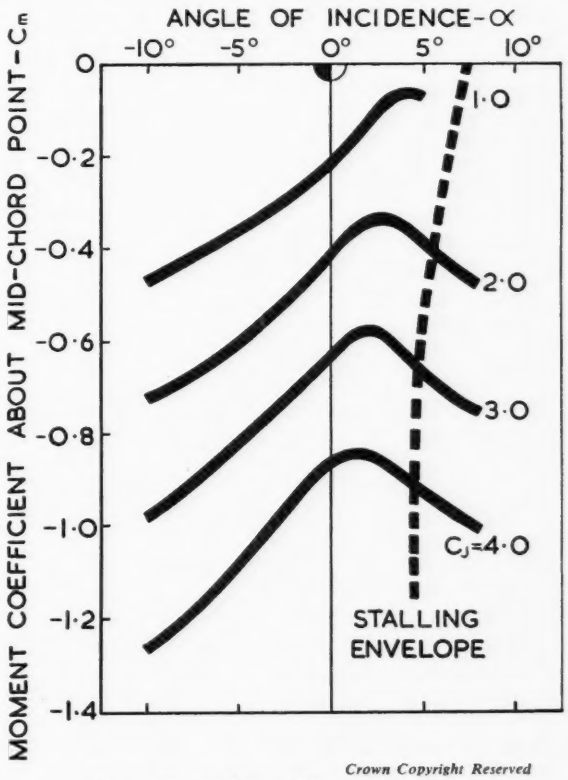

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FIGURE 38. Stalling stability of 31·4° model.

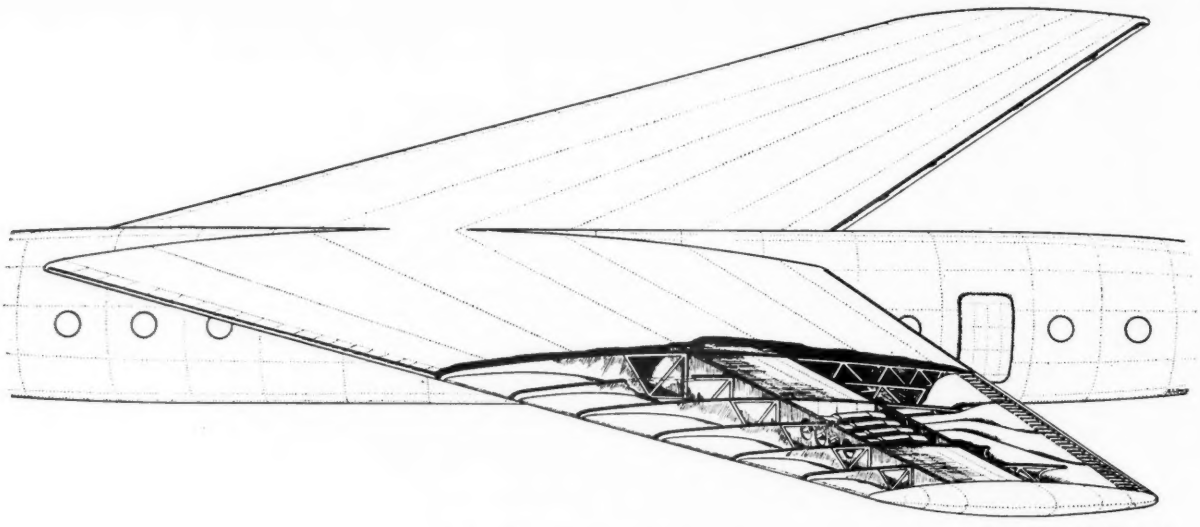

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FIGURE 39. A hypothetical layout.

To reduce to a minimum the overall disturbance following an engine failure, the shroud must clearly be made to do as much work as possible. For example, when a five per cent. shroud is compared at the same angle with a pure jet of C_J value 2·0, it is found to yield fully one-quarter of the lift of the latter. However, in the event of engine failure the unblown shroud would be assisted by the overlapping fields from the neighbouring jets, so that the panel lift would drop not to a quarter, but perhaps only to a half. For this to be possible, however, the shroud itself must be unstalled, and this can be ensured by means of a cold, boundary layer controlling sub-jet which is fed through a manifold supplied by all eight engines.

4. Some Future Possibilities

Having concocted such an arrangement one naturally estimates what it will do for, even with the present state of knowledge, probable orders of magnitude can be discussed. For long range operation the machine might have an all up weight of 150,000 lb., a sea level static thrust of 60,000 lb. and a gross wing area of 2,000 ft.^{2}, with an aspect ratio of 6·0. Then, to yield complete safety with the failure of any one of the six inboard engines, or of both outers, a climb-out speed of about 80 knots would be used. In the event of such a failure the conventional 50 ft. screen might then be cleared in 500 yards while on all eight engines, the corresponding figure would be just over 350 yards.

For a landing weight of 110,000 lb., 35 knots has already been suggested as an ideal minimum figure, but this permits of no contingency allowance. With an approach angle of six degrees and an attitude of nine or ten degrees relative to the ground, a speed of some 50 knots would apparently cope with simultaneous baulking and engine failure, while the landing distance from 50 ft. clearly need not exceed 500 yards.

Since this sort of thing is immediately possible, what about the future? Again, while any recognisable forecast would be imprudent, certain possible trends can nevertheless be discerned. To take one example, there is the possibility of paring down that margin between 50 and 35 knots, for, at the latter figure, a city-centre airport is conceivable even for the 500 knot trans-oceanic aircraft. On the engine side this demands a lessened penalty for failure and, since the eight engines each have four separate cylinders, much could be gained by the judicious interlacing of fuel systems.

Then there is the possibility of using the jet flap principle on propeller-driven aircraft so as to make full use of the slipstream, and in several respects this type of application seems even more promising than that to the pure jet-driven machine. This is feasible in principle because, under take-off conditions, many turbo-prop engines yield about twice the power which they do in normal cruising flight. These days most of that extra take-off power goes to the propellers, but it requires no more than a variable area exhaust slot to extract it instead as additional jet thrust.

There is still, however, the gust handling problem and this raises a possibly impractical, but nevertheless fascinating, idea. In the bird, control is achieved through a nervous system which determines not only the magnitude of its lift and thrust, but also their spanwise distribution. In a typical jet flapped aircraft there may be eight propelling engines, each with its own length of shroud which is capable of producing almost any lift-thrust or lift-drag combination independently of the other seven wing panels. No human pilot could ever hope to make use of this facility, nor would the assistance of the thermionic valve be an economic proposition but, with the coming of the transistor, may not such an aircraft be given ultimately a nervous system of its own?

5. In Conclusion

In this lecture I have attempted to cover a great deal of ground, perhaps too much, but even so it has been possible to mention only a tithe of the discoveries in this new and rapidly expanding field. In fact, I have limited myself to the work of the original National Gas Turbine Establishment team, of which the other members were Dr. B. S. Stratford and Mr. N. A. Dimmock.

To them, I would gladly acknowledge a substantial debt, for without Stratford's theory, Dimmock's experiments could not have been designed and, without those, there would clearly have been no lecture.

Finally, I would emphasise the fact that the investigations just described were not only begun, but were inspired throughout by that crucial observation by Mr. Hayne Constant in November 1952.

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DISCUSSION

PROFESSOR E. J. RICHARDS (University of Southampton, *Fellow*): He thought that they would be doing a great injustice to Mr. Davidson and to N.G.T.E. and to the people there if they were not to look at the very wide significance of this work and indeed to almost learn a lesson from it as to what was going to happen in the future. He thought that it was interesting that Mr. Davidson was an engine man and so were all the other people who had anything to do with this idea. Also, it was interesting that the only other person who in fact had recently put forward this theme of doing things with engines had been Dr. Griffith of Rolls-Royce, another engine man. He thought that whatever came out of the discussion, and whatever happened to the Jet Flap—and he certainly believed that a lot would happen—they had one very big lesson to learn from that happening with two people, from what he thought could be called a conservative set of people regarding airframe requirements—the engine makers. They had, in fact, put forward the idea that no longer could the engine be thought of simply for giving thrust; rather they must think of the engine giving thrust, lift, drag and, for that matter, control. In other words, they were really saying that the engine was now part of the aeroplane as it never was before and that it must be integrated into airframe designs. He thought this so very true that it was worth emphasising.

He thought that Mr. Davidson's lecture in its full concept would be rather wasted if they did not take stock of themselves and see whether or not contacts between engine people and airframe people were sufficiently close to put this whole idea into operation in the quickest possible time. In the past there had been delays on lots of novel ideas, and this certainly was novel. On boundary layer control for instance, progress had been very slow largely because it had been the job of two different sets of people; in this case it was obviously going to be the job of the engine man, certainly the airframe man and the aerodynamics man. He thought the big lesson to be learned from Mr. Davidson, on which they might well take some action, was the need for some body to be responsible in this country for the integration of the engine and the airframe and the structure so as to press on with schemes like this which certainly would not get pressed on with if it were left to just one part of the community to father.

He thought that this was important and worth emphasising and that Mr. Davidson's lecture brought out that big point; it was possibly one that they would look back on in about ten years and say, "This really was the starting point of a new form of integration."

He was sorry that Mr. Davidson did not mention noise. In the British Gaumont News there was mention of noise but only in a half-hearted way, and he would like to emphasise that it was not by any means half-hearted, the advantages that a scheme like Mr. Davidson's would in fact produce. He thought it was true to say that for the engines of the future they could expect fluctuating pressures, noise, near the jet of as much as a half a pound a square inch and as that would occur at frequencies of about 300 cycles it meant that they would be getting a million reversals in just about an hour. The problem of structural fatigue on these new aeroplanes was really going to be great, and it was an interesting point that on a scheme like Mr. David-

son's in which the jet was really being used much more spread out, they could expect noise reductions of 10 or even 20 decibels, that was to say, the pressures would be about a tenth or even a hundredth of the figures that he had mentioned. From the point of view of making practical aeroplanes in the near future it was certainly a point which Mr. Davidson had not mentioned, but really it was an important one.

He believed that the helicopter had a great application in this field but possibly they should not go into that at this stage.

Were there any indications at all of the laws of down wash of the tail?

Another point which came back to his first was that this was going to be very much a job of the engine man, the airframe man and the aerodynamicist. As the engine man, did Mr. Davidson think that the structural and the heating problems were insuperable? Were those problems, and after all he should be able to answer the question on the engine side better than most people, going to be really insuperable for the next ten years?

There had been arguments as to whether or not this scheme was novel. To his way of thinking the scheme was novel in the sense that nobody had really done serious work other than to blow in order to try to make the flap work efficiently. He thought that had been the emphasis every time, except that possibly there had been some patents which probably never had been worked on. Basically, he thought that had been the whole idea whereas this idea was essentially to make the air act as a flap and as such, it was certainly novel. He sincerely hoped that it would not be taken on just as an interesting novelty at the same speed as so many other interesting novelties in the past. If that happened it would be a great shame.

DR. G. V. LACHMANN (Handley Page Ltd., *Fellow*): Professor Richards had already expressed a good deal of what he wanted to say. They had been listening to the presentation of an aerodynamic novelty of fundamental nature; it was indicative of the evolution of a new design philosophy aiming at functional integration of power plant and wings which they were now witnessing in many other respects, that this presentation was made by a gas turbine specialist and not by a professional aerodynamicist. It was obvious that a good deal of deep and hard thinking had made possible the admirable presentation of the jet flap principle. He could follow Mr. Davidson quite well as far as the two-dimensional wing was concerned; but would like to ask some questions on the three-dimensional wing, although he appreciated that the theory of the induced drag of the three-dimensional jet flap wing was apparently still based to a certain extent on inspired intuition.

In Section 2.2 it was stated that in the cruise the value of $\rho_J \times V_J$ approximated closely $\rho_0 V_0$. Therefore, at least in the cruise, one would not expect any sink effect or entrainment and therefore no reduction of induced drag. Now when $\rho_J V_J$ was larger than $\rho_0 V_0$ there was a possible reduction of induced drag due to the sink effect and entrainment on the credit side so to speak, but there was an increase of jet drag on the debit side. When $\rho_J V_J$ was smaller than $\rho_0 V_0$ one had an increase of induced drag due to the source effect on the debit side, and an increase of jet thrust on the credit side. He wondered whether in this aerodynamic balance sheet there would actually be a profit in the end and whether any profit would only be marginal.

In the second part of his lecture, Mr. Davidson very rightly stressed the necessity of a *de novo* approach to the design of a jet flapped aircraft and mentioned as one of the primary design consequences a larger tail than for a conventional aircraft. Since this tail was either a fixed or trimmable one without elevators, laminarisation could be applied to reduce its drag.

Mr. Davidson had mentioned a very interesting and important characteristic of the jet flapped aeroplane, namely, that its handling speed was well below the minimum drag speed. The limitations imposed on handling of conventional aircraft by the minimum drag speed was one of the accepted handicaps of conventional aircraft of the motorised glider type. However, even on conventional aircraft, especially on aircraft of low aspect ratio, great improvements of handling below minimum drag speed could be achieved by an automatic throttle control, monitored either by speed or lift coefficient. The jet flap did this without any additional gadgetry.

Very far-reaching and fundamental changes in design philosophy were generally not welcomed by designers and were met by a pronounced "sales-resistance," unless they helped to solve an acute problem or offered a very decisive advantage. Primarily, the jet flap seemed to promise shorter take-offs and lower landing speeds than the conventional aircraft, and hence one would imagine that short and medium range propeller-driven aircraft should benefit most from its application. It would be interesting, therefore, if Mr. Davidson would expand a little more on the application of jet flap for turbine-driven aircraft and on necessary modifications to engines and propellers. He imagined that the most efficient application demanded the distribution of a fairly large number of turbines along the span, and also that some connection between the jet flap and the pitch control of the propeller might become necessary.

Mr. Davidson mentioned a long range jet aeroplane having a weight/thrust ratio of 0·4, which would seem inherently uneconomical, even if ultra light boost engines were used in addition to the power plant supplying the cruising thrust; besides it seemed to him that for long range aircraft ultra short landing and take-off distances were less essential than for medium and short range aircraft.

Referring to the hypothetical lay-out which Mr. Davidson showed with buried jets, one wondered where the fuel was housed. There seemed to be very little space left for the tanks; fuel tanks in close proximity to hot ducts did not seem to be a very attractive solution.

From the military point of view the jet flap might be of particular interest for short range troop carriers which had to land and take off in unprepared airfields in the combat zone.

The secondary advantage of the jet flap in regard to

noise had already been mentioned; another, which was also of great importance, was gust alleviation.

Mr. Davidson had presented a great deal of stimulating, but also somewhat controversial, food for thought.

L. F. NICHOLSON (Aerodynamics Department, R.A.E., *Associate Fellow*): He would like to claim both Mr. Davidson and, he thought, Dr. Griffith as professional aerodynamicists albeit working in the engine field. It was up to Mr. Davidson to deny that if he liked later on, but he insisted in claiming him as an aerodynamicist.

One of the dreams of any scientist or research engineer must be to find some new problem on which to work, where simple experiments and approximate theory backed by insight and imagination could make really great advances, rather than to tidy up the details in a field which was generally well understood. Mr. Davidson and his team were, he thought, to be congratulated very much on finding such a problem and also on the brilliant way in which they had seized their opportunity and really opened up this new field.

A great many experiments were needed to consolidate the field and many of them would be difficult and inevitably slow, but he hoped that the work would be tackled on a fair priority in relation to other things and on a wide enough front.

One outstanding problem in the experimental field was the extension of this type of experiment, both two- and three-dimensional with various geometries to the higher Reynolds numbers and he thought that was particularly important as far as the thrust balance was concerned. He thought the thrust balance might turn out to be quite an important part in this overall balance sheet when it came to getting a real aeroplane. The difficulty was that if they wanted to get high Reynolds numbers by large size then the auxiliary blowing plant required to produce the jet was large, the manufacture of the models was expensive and so was the design. If a high Reynolds number were obtained by using high pressures then the stressing of the model became almost impossible. All one could say was that one lesson to be learnt from current developments in general, and from this lecture in particular, was that in designing new low speed tunnels for research it was clear that sizeable auxiliary compressors and general auxiliary compressing and suction plant must be considered from the beginning.

Considering the jet flap, not as a problem of fluid motion, but as another device which an aeronautical engineer had in his locker, he felt that it was too early to get a proper assessment of the place of the jet flap and its importance relative to all these other devices for combining the lifting and thrusting parts of an aircraft. On the other hand it was important to get this assessment as quickly as possible and he hoped as wide a circle as possible would play about with the idea of this jet flap. He hoped that Mr. Davidson could help in assessing the weights of the various schemes which might be proposed because ultimately the weight of such schemes was very often the thing which made the difference between a real success and something which was marginal.

Having asked for all this project work, some of which was already well in hand, he would ask that the people doing it would consider the weights and practical engineering problems and not forget several points. First that flaps did work; they were relatively light and simple if the flow could be made to flow round them. Secondly, that large wing area was a most successful high lift device; he hoped they would not seek lift coefficient rather than lift. Thirdly, that aspect ratio was important in all high lift devices, and high induced drags could be associated with high lift coefficients and low aspect ratios, whether or not the jet flap were used. Fourthly, the more controversial point, that the circle was a natural shape for a jet; it was a natural shape for an engine and the engine thrust in cruising flight was something which must not be compromised seriously in order to improve the landing and take-off. What sort of losses might they expect from forcing the use of types of engines suitable for jet flaps and from the ducting between the circular engines to the exit slits.

The great importance of the possible unstallable qualities of Mr. Davidson's aircraft, and the noise, were other points to remember. He was interested in the reduction of noise from the public reaction rather than the structural point of view, because he believed that the type of aircraft to which this kind of idea was practicable would not necessarily be quite as noisy as Professor Richards suggested. He thought that the use of ducted fan engines in themselves, without the flapped jet, would go a long way towards reducing the noise.

Mr. Davidson had referred to the change in frequency. Even when the noise was reduced to something which did not worry the structure, or possibly the structure was stiffened up until it could stand the noise, he wondered if there would be any implications in changing the noise to a shriek instead of a roar.

Although perhaps he had made one or two damping remarks, in emphasising the alternatives or competitors to the jet lift idea, they were all very grateful for having this new brick with which the designers could build, this new idea with which they could play; he was sure that the right application would be found.

PROFESSOR H. B. SQUIRE (Imperial College, *Fellow*): He asked about the induced drag of three-dimensional wings using the jet flap. It seemed unlikely that this induced drag D_i could be very different from the standard formula for wings with elliptic loading, namely

$$D_i = 4L^2/(\pi\rho V^2 b^2)$$

where L was the wing lift and b the wing span. An appreciable increase in effective span due to the jet seemed improbable.

E. PRIBRAM (Fairey Aviation Co. Ltd., *Associate Fellow*): Internal duct losses were essentially due to the necessity of changing the duct shape from a circular one at the turbine end to a relatively narrow slot; and would be mainly vorticity and corner flow effects. A rough estimate of the losses for an arrangement such as that shown in Fig. 39, had led to a figure of the order

of 20 per cent., or twice that given by Mr. Davidson. He therefore believed that a separate jet pipe would have to be used in cruising flight.

Turning to the control mechanism proposed, he noted that on page 29 Mr. Davidson had stated that "under high lift conditions, large variations in the jet angle can produce rather unpleasant effects—certainly bad handling characteristics and possibly a catastrophic stall—so that $(\partial C_L)/(\partial\theta)$ can conveniently be forgotten." It was then somewhat disturbing to find on page 36 that this was the method of longitudinal control adopted.

Apart from this, he thought that the suggested method of longitudinal control would prove unworkable in practice. A change in incidence, due to an up or down gust or an alteration in aircraft attitude, was to be compensated by an adjustment in jet lift effect. As Fig. 38 showed, a negative pitching moment increase was obtained by increasing the jet lift; hence an increase in incidence with the consequent increment in positive C_m had to be corrected by an increase in jet lift, thus further increasing total lift. This was presumably meant by "a ballooning of the aircraft" referred to on page 37. With a down-gust, the effects would be reversed, and he felt sure the consequent rapid downward displacement of the aircraft would be unacceptable, particularly at low altitudes.

A similar condition, of course, applied with conventional elevator controls, but he thought the fundamental difficulty of Mr. Davidson's scheme stemmed from the replacement of a small control force acting at a large moment arm by a very large force acting on a small arm. Obviously, means could be found to overcome the lack of elevator efficiency at the very low speeds envisaged, but they might seriously complicate the design.

In general, he felt Mr. Davidson had been overimpressed by the importance of having an aircraft that could not be stalled. What they were really interested in was rapid and accurate response to control application, particularly at low speeds. He did not think the means suggested met that requirement.

On page 40, he had not been able to follow the argument about the use of the slipstream in the last paragraph. While it might be possible to divert part of the power of a turbo-prop engine to create jet thrust instead of propeller thrust, this seemed to have no connection with a slipstream effect.

The explanation offered for a reduction in induced drag of a jet flapped wing on page 35 appeared to be wrong. The sink effect of the jet—what Mr. Davidson called "getting to grips with more than the usual mass flow"—was utilised to increase C_L; it could not then be used a second time as an argument for increasing the propulsive efficiency. One would expect the induced drag, apart from a small difference due to the lift generated by the pressure difference at the slot, to be exactly the same as that of any wing having the same aspect ratio.

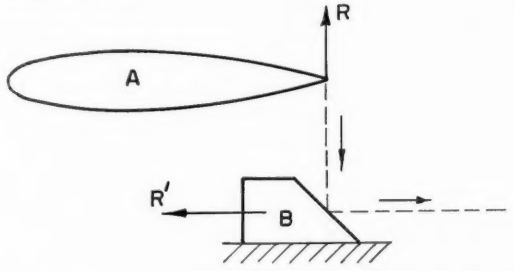
On page 26, the jet flap was compared to a Fowler flap; this was a slotted flap; surely the right comparison was to a chord extending split flap—usually called a Zap flap.

There was a mistake in the translation of the quotation on page 35. The second sentence should read: "The pressure difference probably extends along the jet sheet into the main stream and is used to turn the jet sheet into the original flow direction."

From his remarks, it might appear that he was critical of Mr. Davidson's idea. That was not so; he thought that the basic scheme was perfectly sound, but that the application to the design of an aircraft, as discussed in Part II of the lecture, would require considerable modification.

DR. S. NEUMARK (Royal Aircraft Establishment, *Fellow*): He was doubtful about Mr. Davidson's approach to the problem of the propulsive thrust in the jet flap system with varying jet angle θ. The theorem given in Section 2.1 seemed fallacious because the application of Newton's second Law did not seem to be a legitimate one, and this led to questionable conclusions, especially for large values of θ.

The particular case $\theta=90°$ might be considered for simplicity. Let it be assumed that the body A (*see* figure) ejected particles vertically downwards. The reaction R on A would then be directed vertically upwards. If the particles hit another body B and rebounded to move horizontally backwards, there would be a forward horizontal reaction R' acting on B, but not on A.



The case of a jet flap system with $\theta=90°$ was analogous to the previous simplified scheme. In the absence of relative wind there would, of course, be no backwards deflection of the jet, and hence no thrust component whatsoever. With relative wind present, the jet was gradually deflected backwards owing to a continuous series of impacts against particles of the oncoming stream below the aerofoil, and those particles received a forward impulse. The stream slowed down, the pressure increased, and this produced the jet-induced lift. There seemed to be no clear mechanism to transfer even a part of the forward reaction (let alone the entire reaction) from the air particles to the aerofoil. The correct application of the law of momentum must include not only the aerofoil and jet particles, but also the air particles of the relative stream. The theorem of Section 2.1 did not logically follow, although there was a possibility that some small propulsive thrust might be created indirectly through the complicated mechanism of the induced pressure distribution. Mr. Davidson's argument referring to Fig. 22, where considerable suction at the nose was put forward as the origin of propulsive thrust, seemed therefore more convincing,

but it was difficult to see how this thrust could reach the full value of J. Even the figure 0·3 to 0·4J seemed surprisingly high, and more than one or two "quite crude experiments" were needed to substantiate the lecturer's point. Instead of expecting the propulsive thrust to be nearly equal to the total jet reaction J, one should rather consider even a small fraction of J recovered for propulsion at $\theta=90°$ as an unexpected windfall.

Another debatable point of the lecture was the proposal to dispense with the elevator and to control the jet flapped aircraft longitudinally by changing either θ at high speed, or C_J at low speed. This seemed hazardous in view of the unpredictable response characteristics with these novel types of control. The elevator affected directly only the pitching moment which produced a gradual change of incidence and thus the required lift increment, with only a small and smooth variation of speed. Control through jet augmentation or deflection would act in a completely different way, namely, it would affect directly lift, pitching moment *and* thrust, all at the same time. The jet-induced lift might be increased rapidly, but then the nose-down moment would create a negative incidence and hence possibly large negative lift increment when least expected. The changes in propulsive thrust would be another unusual feature, tending to accelerate (or decelerate) the aircraft when lift was augmented by increasing C_J (or θ). A host of complicated and hitherto unknown problems thus arose, not only for the designer and his mathematicians, but also for the test pilot who would be confronted by a response completely different from all his previous experience. Would it not be safer and more prudent, at least in the beginning, to endow the first jet flapped prototypes with conventional elevator control?

N. E. ROWE: He was sure they would all agree that it had been a most stimulating and valuable lecture and discussion. The lecture had really been a report of the work of a team and, as others remarked, it was done in an extraordinarily clear and lucid way and they obtained a clear picture of what was in the lecturer's mind and of the work which had been done. Obviously, there was a great deal of controversy as to the value of this and of how it should be best used but he rather felt with Professor Richards, and he thought others, that there was a great deal of value here which should be pursued and, as the lecturer suggested, they should try to do it by simple experiments, as the lecturer had done, rather than rush too soon into full scale work.

DR. J. WILLIAMS (National Physical Laboratory, *Associate Fellow*) *contributed*: In Section 3 of Part I, Mr. Davidson rightly drew attention to the lack of experimental data on the effects of finite aspect ratio on jet flap wings. At the end of 1953, some exploratory tests were made at the N.P.L. on a pressure-plotting model to determine the order of magnitude of such effects, particularly as regards lift. The model, which had a rectangular plan form of aspect ratio 3 and a 30° jet angle, was of the same family as those tested under two-dimensional conditions at the N.G.T.E. and was, in fact, fabricated there.

With T.E. blowing and the wing at zero incidence, the spanwise distribution of the *pressure-lift* loading (obtained by chordwise integration of the surface static pressures) followed closely that which would be expected on a conventional wing at incidence, *i.e.* a near elliptic distribution. Moreover, for C_J values up to unity, the *total lift* (pressure lift + vertical component of jet reaction) on the aspect ratio 3 wing was roughly three-fifths of the two-dimensional values. The *pressure drag* on the wing, arising from downwash effects, was not much larger than would be expected for a conventional wing at incidence giving the same pressure lift. It was also encouraging to find that in these experiments the stalling angle of the lift-incidence curves (C_J constant) decreased little as C_J was increased.

In the assessment and development of the jet flap scheme, it should not be overlooked that the C_J (or C_μ) requirements to produce a moderate lift by blowing (boundary layer control) on a plain T.E. flap of normal size might well be only one-tenth of those needed with the simple jet flap at the same angle. Thus, from an aerodynamic point of view, the use of compressor bleed or other motive power for T.E. flap blowing, together with the normal methods of producing thrust, should not be rejected out of hand for applications where C_J-values up to about unity were envisaged. At higher C_J-values, there might also be some advantage in combining boundary layer control on T.E. flaps with the jet flap scheme.

A. R. METTAM (Royal Aircraft Establishment, *Associate Fellow*) *contributed*: Mr. Davidson had referred to proposals which he made in 1948 to vary the lift on aerofoils by ejecting air from spanwise slots. The primary object of his proposals had been to overcome high-speed control difficulties by eliminating hinged surfaces. For various reasons, the idea had not been taken seriously at that time, but he had done basic research himself which culminated in detailed design studies for a test wing. As a result, he felt able to suggest likely trends in the practical application of the jet flap principle.

In his work the source of ejection fluid was ram-air, but his proposals covered the "boosting" of this supply by engine-induction, on the injector principle. This might be the best method of providing the jet efflux, since temperature problems would thereby be minimised.

It seemed unlikely to him that throttling of jet units could be used as a control means, because of the delayed response. Variation of the jet angle was also unlikely to be very practical; even with a 3 per cent. chord shroud, the hinge moment would be enormous and either a large fuselage-mounted power unit or a number of smaller units would be needed to rotate the shroud. However, if "boosted" ram-air were controlled by a sliding-gate type of valve immediately before ejection, with the slide moving substantially normal to the flow, then response should be satisfactory and power-operation eliminated.

In this connection, his work had shown adequate

control to be obtained with ejection slots equal in length to normal ailerons. That was with "unboosted" ram-air; with engine-induced flow, the span fraction required for control might be as low as 10 per cent.

He thought that intake and ejection ducting must run chordwise; even so, the dynamic head lost would be some 15 per cent. If spanwise ducting were used, with its attendant corners, the loss would rise to over 30 per cent. He must side with Mr. Pribram in thinking that the lecturer's total loss estimates were far too optimistic.

The immediate need was for three-dimensional tests of the jet flap principle. To be realistic these had to be at full-scale Reynolds numbers; he thought the lecturer had underestimated the effect of this parameter on duct losses. Mr. Nicholson had explained the difficulties of tunnel testing at high Reynolds numbers; might not the answer be flight tests on a conventional aircraft with modified wing panels and using ram-air for the jet? An independent authority had advocated such tests in 1953 and his own test wing design, completed in 1950, would be readily adaptable to this end.

The paper had produced a number of ideas which were not amenable to treatment by existing theory. There was bound to be much scepticism as a result. Theory, however, was only of value when based on firm experimental data rather than on the preconceived ideas of scientists.

One of the most powerful arguments put forward by the "conventionalists" would be that the jet flap was not worth developing since it could not readily be applied to the thin wings which were currently thought to be essential for supersonic aircraft. However, a configuration which would be ideal for the jet flap aircraft was a thin-wing biplane, of narrow gap and having a series of turbo-jets and ram-jets distributed along the span. The supersonic drag of such a configuration could be made small by careful design, as shown by Busemann.

The remaining problems of application of the jet flap principle were purely engineering ones. It was in this field of translating promising ideas into actual "hardware" that Great Britain had fallen behind in airframe design. They tended still to argue over niceties of mathematical theory while other countries were flying a test aircraft, albeit crude, and establishing physical facts. He hoped that the jet flap would not be yet another case of infanticide at the hands of the over-academic.

He would perhaps emphasise that the views he had expressed were his own and did not necessarily represent those of the R.A.E. Similarly, his researches into air-ejection were conducted completely privately and the report on them did not have the backing of the R.A.E. The Ministry of Supply had, however, taken over his cover patent on air-ejection controls.

A. S. TAYLOR (Royal Aircraft Establishment, Farnborough, *Associate Fellow*) *contributed*: He was not sure that he followed the arguments that led Mr. Davidson to suggest that in a jet flapped aircraft the conventional elevator system should be abandoned. At the present stage of development, a designer who was incorporating such an unorthodox feature as a jet flapped aerofoil in his design, would presumably like to keep it as conventional as possible in other respects. Thus, he would probably like to employ a conventional elevator (or all-moving tail) control system if it would work. Was Mr. Davidson suggesting that, in fact, it would not work at all? He hoped not because he had recently completed an investigation which purported to show that, subject to certain conditions, the conventional elevator control was a practical proposition.

Perhaps Mr. Davidson was only suggesting that the alternative method of control which he advocated would work better than an elevator. If so, was it not premature to talk of abandoning the latter? Should they not, at least, keep it in reserve against the possibility that Mr. Davidson's alternative proposals worked out less well than he anticipated?

In arriving at his conclusions about the stability and control of jet flapped aircraft, the lecturer seemed to have dispensed with mathematics and relied on rough physical arguments compiled with a certain amount of intuition.

To one who found it difficult enough to make a correct assessment of such problems, even with the aid of the full mathematical treatment, this seemed a risky procedure and, personally, he would not like to venture an opinion on the validity of Mr. Davidson's conclusions without making a thorough mathematical investigation of all the possibilities.

DR. B. THWAITES (Winchester College, *Associate Fellow*) *contributed*: One of the most interesting and valuable outcomes of the Jet Flap discovery was the variety of associated problems which were suggested. To two of these he would particularly like to draw attention.

The first was the boundary layer entrainment effect It was not enough to calculate the potential flow outside the boundary layer and to deduce the growth of the boundary layer from it. Near the jet, the curvature of the streamlines was large, so were the pressure gradients across the boundary layer and there was then "upstream influence" within the boundary layer itself.

Secondly, there might be startling additional gains to be achieved by proper design of the jet-flap aerofoil. This suggested the extension of existing methods of aerofoil design (in potential flow). Such ideas would apply mainly to slow aircraft since for high speed aircraft, a thin wing was obligatory and offered little scope for alteration of shape.

The jet flap principle, since it incorporated the agency of lift with that of thrust, probably superseded his own flap idea, which coped with the thrust problem by reducing the drag to zero. He was not sure whether the advantage of the latter was being applicable even to, say, circular cylinders, was shared by the jet flap; probably each idea would find its own specialised application in ten or twenty years' time.

E. S. J. KRAUSS (*Associate Fellow*) *contributed*: He was most interested to hear of the work that had been done to investigate the effects of the Jet Flap on the

aerodynamic characteristics of aerofoil sections and it was even more interesting to hear about the consequent increase in lift, which, as the author concluded from his experiments, corresponded to the lift of an aerofoil section with a flap chord of one hundred and fifty per cent. greater than that of the aerofoil section used in the experiment in combination with the jet.

Since any wind tunnel would introduce a constraint of the flow pattern, it would be of interest to know whether any attempt was made to investigate the magnitude of this effect and to correct for it in the results presented in this paper?

MR. DAVIDSON'S REPLY

PROFESSOR RICHARDS: He thanked Professor Richards for his encouragement and was glad that he had pointed out the fact of the noise being reduced. He had not put that point in the paper because at the time of writing it was a rather controversial, indeed one might almost say a political, issue!

One significant point that Professor Richards did not bring out was that as well as the reduction in the decibels, or the noise level, the noise would be pushed right up the frequency spectrum so that quite a change could be expected to follow on that account. In connection with the engineering difficulties, one would naturally envisage as much change in the engine as in the aircraft; there might perhaps be a marked reduction in jet temperature through the use of by-pass engines, or engines of that ilk, which would also bring about a lower jet speed and, as they all knew, the noise went down at something like the eighth power of the jet speed.

He had made no attempt in the paper to indicate what the downwash at the tail would be because he felt that he really would be trespassing if he went that far. After all, he was an engine man; but he had naturally made his own estimate and so far as he could see on, for example, the Comet replacement example the maximum C_L to trim on the tail should be round about unity —in the negative sense.

DR. LACHMANN: He confessed that Dr. Lachmann had hoist him with his own petard! There was no mistake in the paper, but when he introduced the nomenclature of $\rho_0 V_0$ and $\rho_J V_J$ he was rather afraid people would be confused; but he had got tied up himself. He could not understand Dr. Lachmann's question, but thought he could still answer it because he still had one or two tricks up his sleeve. The first was that so far no mention had been made of what happened to the aircraft boundary layer except under very high lift conditions, where the effects were not vital. In cruising flight, as would be shown in Stratford's work when it was published, a lot of interesting effects were possible.

For example, the mixing process could, in theory, remove the form drag on the wing; although he agreed entirely with Dr. Lachmann that there would be no reduction in induced drag under cruising conditions. He was sorry if he had given that impression in the paper. There, he was really concerned with the take-off and landing cases, where the whole secret of getting the maximum lift was to get the minimum induced drag, because all the thrust which could be generated was required to push the aircraft along. So far as the cruise was concerned he would not like to go into detail now, except to say that there were these boundary layer effects and that he thought that the overall account book would look very much like that for a conventional aircraft. There would perhaps be less thrust because of internal losses, but there might also be a bit less drag.

With regard to the tail laminarisation he could only thank Dr. Lachmann for drawing attention to the fact that the jet flap seemed to fit in quite well with Dr. Lachmann's own thesis of laminarising the whole aircraft. Only, he was afraid that if this were done they would be left with no thrust at all and would certainly have to put in boost engines.

He believed that Dr. Lachmann had already dealt fully with the so-called "q" control in his own recent lecture[1].

Turning now to propeller-driven aircraft; this was a subject in itself and one suffered at the beginning from the fact that the basic scientific problem of what lift could be generated in the presence of a slipstream had not yet been solved. The best one might do at the present day, for example, was to assume that the slipstream was an artificial main stream and base one's coefficients on that; then one found that, although very large lifts were obtained, the lift coefficient based on the slipstream velocity might only be of the order of two and a half or three, which was quite easy to obtain by more conventional methods. Thus it rather looked as though the ultimate application to the propeller-driven aircraft might only come about when the jet aircraft problems had been solved and development had been taken to the stage at which it was less expensive in weight and effort to incorporate a jet flap than to put on a conventional flap with boundary layer control.

Concerning the thrust to weight ratio of 0·4, he was afraid that he omitted to mention in the presentation of the paper that the engines were by-pass engines; and he thought that if this were borne in mind it would be seen that thrust to weight ratio at take-off and landing with the same economical cruising thrust could be much larger than it was today—unless the aircraft were fully laminarised, when his previous remark would apply.

He confessed that the fuel tanks and their possible proximity to the engines were a difficult problem, but he had only put forward one example as the sort of thing which could be envisaged immediately. One of the things he had not discussed at all, and of which he thought Dr. Griffith would approve, was the idea of doing away with the tail altogether and using jet stabilisation. If that were done, one could not at present foresee whether the best aircraft would have a conventional wing and tail or whether it might, for example, be a flying saucer. All that was needed in principle was a large area on which to induce the lift and some means of stabilisation. There were several ways of stabilising an aircraft and, so far as he knew, nobody had yet looked sufficiently far ahead to take them all into account, so that at the present time just where the fuel and the engines would go in the ultimate machine could not reasonably be argued about.

(*Mr. Davidson later added in writing*)

For lower speed aircraft his argument was, of course, facetious, since a high aspect ratio would be vital for good economy; but then so also would be the propeller or low temperature ducted fan engine and, on account of the limited range, much less fuel would have to be stored.

Concerning the propeller engine; it was well known that the power of a reciprocating engine dropped off with increasing altitude and that this effect could be counteracted by using a supercharger. Thermodynamically, such a process was also effectively possible with the high efficiency, double-compound, turbo-propeller engine.

Were such an engine to be designed for the most economic cruising performance in the stratosphere, its power in low speed flight at sea level might greatly exceed that which could be absorbed by the most economic reduction gear-propeller combination. Thus, under take-off and landing conditions such an engine might well be run thermodynamically and aerodynamically derated—*i.e.* without its supercharge.

However, provided that the excess power was extracted as jet thrust rather than as shaft horsepower, the full degree of supercharge could be used at sea level to yield a power unit which was half turbo-propeller and half turbo-jet. Naturally, as Dr. Lachmann had implied, a reduced propeller pitch would be required in these circumstances.

MR. L. F. NICHOLSON: He wished to thank Mr. Nicholson especially for raising all the points that he had, and agreed with him in almost everything he had said.

Concerning the experimental difficulties, he certainly agreed that he would not like the problem of designing large scale wind tunnel experiments. But he did not think that one could emphasise too much the fact that, whereas the thrust-drag balance depended very much upon Reynolds number effects, the effect on the lift of the Reynolds number under very high lift conditions might well be remarkably small. He would suggest that quite a lot of progress could be made by doing the work on lift at lower Reynolds numbers and not by embarking on full-scale investigations at this stage into the thrust-drag process at all, but rather by investigating the fundamental details of the entrainment process and the rate of mixing and so on in what amounted, figuratively if not literally, to experiments in glass tubes on a University bench. He thought that one could go a long way with those techniques and he hoped that people in such laboratories up and down the country would play their part, because when they had those fundamental bricks well and truly understood, they could soon be built up to form a picture of the thrust-drag balance on the whole wing.

He had not yet answered Professor Richard's question about the structural and heating problems, nor Dr. Lachmann's about the engine component weights, and so on. He had sidestepped these rather by bringing in the point of by-pass engines; but now in answer to Mr. Nicholson and also to the previous speakers, he would mention that, even if the whole jet deflecting mechanism were run in the hot gas stream from a modern jet engine, the temperature would still be considerably lower than that which was encountered by the turbine blades themselves which, of course, usually operated in a centrifugal field of perhaps 50,000 *g*. The fact remained that gas turbines did work, and whereas there would undoubtedly be all kinds of difficulty that could not at present be foreseen in the design and development of these jet deflecting mechanisms, there was no doubt whatever in principle that they could be solved. The problems were less severe than some of those which had already been solved in the engine itself.

It was difficult to give a firm estimate of loss of thrust at cruising speed. Those in the engine field still had experimental work to do on the internal aerodynamics, for so far they had studied only the field in which the aircraft and engine fluids met. But, at a rough guess, he thought that there was no doubt whatever that something like ten per cent. of the net thrust might go in internal losses, and he could only say that the answer would lie in the overall balance at which he hinted when he mentioned the boundary layer-jet interaction effects in answer to Dr. Lachmann. After all, all that mattered was that the aircraft would fly with a minimum fuel consumption. It did not matter what the thrust or the drag were individually.

(*Mr. Davidson later added in writing*)

In the verbal reply scant justice was done to the significant detail of Mr. Nicholson's contribution, of which the first point concerned his professional activities. In gas turbine research it was true that one engaged seriously at times in diverse fields, including that of aerodynamics, but this did not alter the fact that one still was primarily, and practised as, a mechanical engineer.

The first of Mr. Nicholson's four engineering points was undeniably sound and was implicitly admitted in the reply to Dr. Lachmann, but the second was surely a trifle naïve! In sound commercial operation overall economy and nothing else must be permitted to dictate the wing loading and, if in some instances this should transpire to be rather low, so much the better for the jet flap—it would facilitate a minimum speed of 30 knots instead of 40.

The next two points were of considerable consequence, for both bore in novel directions upon the engine design. Since the engines must be distributed over the span and also buried, the need for a high aspect ratio on subsonic aircraft automatically meant the use of a large number of rather small units and so put a premium on the life between overhauls. On the other hand, the whole question of duct shape and size boiled down in the end to the permissible pressure loss and weight penalty, and from the controversy between these two might well emerge the ducted fan engine with its inherently low duct stress and temperature.

This type of engine was explicitly suggested by Mr. Nicholson himself, but it was important to realise that, while the arrangement had been known since the earliest days, it had been repeatedly and properly rejected on

the score of duct losses. However, with the advent of the jet flap the "carrot" had grown enormously, for not only did it now represent a virtually silent aircraft of high efficiency, but also one which combined those attributes with an ultimate speed range of ten to one, or more! But this result would be achieved only with the strictest design discipline, for it seemed likely to involve an engine aerodynamic "snowball" which was at least as virulent as the well-known aircraft structural one.

Lastly, if despite these possibilities there came to pass a jet flapped aircraft with a high speed jet, the advantages of the shriek as opposed to the roar might be found to be threefold—much of it would be ultrasonic, all of it would be more rapidly attenuated by the atmosphere and, with a shrouded jet flap, it might conceivably be beamed so as not to reach the ground near the aircraft.

PROFESSOR SQUIRE: If the results quoted by Dr. Williams be combined with the data given in Part I of the lecture it might fairly easily be deduced that, in his experiment at aspect ratio 3·0, the induced drag was at times not much more than 80 per cent. of that which would be expected of a corresponding "conventional" wing with the same *total* lift. Again, while Hagedorn and Ruden[4] gave no measured drag values, it was possible to extract from their results evidence of a qualitatively similar effect at an aspect ratio just over four. Two different physical explanations were mentioned in the lecture and in pursuing those one could not do better than refer to Lanchester's original analysis*.

However, since those arguments relied solely upon the jet entrainment effect, they necessarily represented only a part of the real explanation. The other—potential flow—part might presumably be sought along the following lines.

Under very high lift conditions the lift gain, G, would be small, as was shown by Figs. 9 and 10 of the lecture. Thus, considering the influence on the main stream, the total strength, $(J \sin\theta)/(\rho_0 V_0)$, of the vortex sheet representing the real jet would be of the same order of magnitude as the "circulation" $(L - J\sin\theta)/(\rho_0 V_0)$ on the body of the aerofoil. But in a three-dimensional system this vorticity in the jet sheet would be shed at chordwise stations aft of the aerofoil trailing edge. Hence, the total shed vorticity being the same in both instances, there was no reason to suppose that the downwash angle in the vicinity of a jet flapped aerofoil would be quite the same as that in the vicinity of a corresponding conventional one.

Nevertheless, with subsonic aircraft of high aspect ratio the reduction in induced drag might, as suggested by Professor Squire, be small. But for supersonic aircraft the use of a pure jet lift had already been suggested and so since it would seem wasteful to discard any jet flap effect which could be obtained gratis, the possibly substantial induced drag reduction on low aspect ratio wings might not be without practical significance.

MR. PRIBRAM: Mr. Pribram might indeed have found a loss of the order of 20 per cent., for, while the duct dimensions in his study were presumably based on Fig. 39 of the lecture, the corner or secondary loss in a circular duct varied inversely as the fourth power of its diameter! However, he was morally correct, for much remained to be done towards cleaning up the internal aerodynamics.

Mr. Pribram's next point was incomprehensible, since the "offending" passages of the lecture—Sections 1·3 of Part I and 1·3 of Part II contained the following, mutually exclusive descriptions: "under high lift conditions" and "in high speed flight."

The criticism concerning longitudinal control involved no logical fallacy, but appeared to be based upon two debatable premises—that the aircraft had no tailplane or fuselage, and that its ground attitude was vital. Concerning the latter, it was to be assumed with the proposed form of low speed control that the ground attitude of the machine would be permitted to wander within reasonable limits, the undercarriage being designed accordingly should a last minute correction at touchdown prove impracticable.

So far as the response rate is concerned, this should be at least as rapid as on any conventional machine and should increase with the c.g. margin—*see* Section 1.3 of Part II and Fig. 36.

In a propeller-turbine system the engine exhaust C_J value based on the slipstream velocity would be of the same order of magnitude as that in Fig. 14(*a*), where the main stream was visibly contracted and thrown down behind the aerofoil. From the reply to Dr. Lachmann, it would be seen that there was as yet no analysis of a field containing a slipstream, so that no one could say just how much lift would be generated. However, it was not difficult to see that it could be significantly more than that indicated by a simple calculation in which all the coefficients were all based on the slipstream velocity, and this must be regarded at present as the most important unsolved fundamental problem concerning the jet flap.

The induced drag question had already been discussed in reply to Professor Squire and the next point concerned the technical description of the analogous flap. The latter was an essentially mathematical concept—derived from thin aerofoil theory—and was therefore strictly applicable only in potential flow. So far as the jet flap was concerned this was fair enough, since boundary layer control was provided automatically by the jet entrainment effect. Hence, if the concept must be given a practical twist, the analogous solid flap should either be provided with boundary layer control, or should be slotted for near-potential flow operation at substantial angles of deflection.

So far as the translation from German was concerned, the question was simply one of English idiom and most people naturally preferred their own. Historically, only the original should be considered.

*The flying machine. Proc. Inst. Automobile Eng., Vol. IX. March 1915.

DR. NEUMARK: Consider the flow inviscid and irrotational with two thin flexible membranes separating the jet and main stream fluids and being capable of transmitting only normal pressure forces. Mathematically, these membranes could be treated as vortex sheets and, if their local strengths be γ_1 and γ_2, the jet main stream stability criterion would be

$$\gamma_1 - \gamma_2 = \frac{J}{\rho_0 V_0 R}$$

where R was the local mean radius of curvature. When the solution of this equation was used in place of the Kutta-Joukowski hypothesis all else followed—including Stratford's thrust hypothesis.

However, an exact mathematical analysis naturally offered much technical difficulty and, provided only that the thrust hypothesis and not the whole pressure distribution was required, this could be obtained by simple logic using the same basic trick—two thin flexible membranes. The justification for the term "jet-drag" was that, barring viscosity at the aerofoil surface, only the effects of the jet mixing process could produce a net forward force on the aerofoil of magnitude less than J.

The mechanism which Dr. Neumark declared he could not conceive was thus none other than the upstream influence spreading process in potential flow.

He agreed wholeheartedly with Dr. Neumark's closing remark, but could detect in his earlier comments on stability and control no more than an understandable preference for devils known.

DR. J. WILLIAMS: So long as present-day aerodromes were tolerated, Dr. Williams would be right and there might be no place for the jet flap. In the usable lift coefficient spectrum there was no single point through which a line could be drawn between conventional and jet flapped aircraft, but the transition region must surely lie in the vicinity of 3·5!

MR. METTAM: Mr. Mettam's views were both interesting and stimulating, but one must consider the appalling fundamental inefficiency of the injector pump as compared with the ducted fan engine which, after all, did much the same thing thermodynamically.

So far as control delay was concerned, what about the "bedstead"? With a well designed engine running in the region of its maximum continuous rating the response should be extremely rapid. Again, with good design the hinge moment of even a ten per cent. shroud could be reduced in theory to a very small value, and the real practical problem might even be the introduction of sufficient feel.

Finally, in answer not only to Mr. Mettam, but to all who had correctly raised the question of duct losses, it should be stressed that, in the opening remarks of Part II of the lecture, the example was described as no more than "a first, simple expedient."

MR. TAYLOR: Mr. Taylor was quite right—he would refer them to the opening sentence of Part II of the lecture. But this in no way affected the argument that the proposed, or some other novel, control system would in the end prevail for reasons stated or implied.

Indeed, in this connection it would be interesting to know just what constituted "the full mathematical treatment" and just what approximations the latter was likely to conceal. As with logic, no amount of mathematics would compensate for a false premise, and it had even been "proved mathematically" that the jet flap aerodynamic mechanism was impossible! Were a full mathematical treatment without approximations really practicable, he would accept none other.

DR. B. THWAITES: The boundary layer effect to which Dr. Thwaites referred was, of course, the source of both the "automatic boundary control" and the form drag removal process already mentioned, so it would certainly repay close study.

His second point was an attractive one, but seemed likely to depend in the end on the success of the ducted fan engine, for were a high speed jet to be emitted anywhere but close to the trailing edge the skin friction loss and turbulent heat transfer to the structure would both be excessive.

MR. KRAUSS: The answer to Mr. Krauss's question was implicit in Fig. 21 of the lecture and was the reason why the wind tunnel working section was given the unusual proportions of 5×1. With the 58·1° jet angle the effect could be to reduce the lift by about one per cent., or perhaps two, but since the theory was inviscid while the real flow was as in Fig. 14, the matter was not pursued.

Flow Studies of the Leading Edge Stall on a Swept-Back Wing at High Incidence

by

JOSEPH BLACK, Ph.D., A.F.R.Ae.S.,

(Department of Aeronautical Engineering, University of Bristol)

SUMMARY:—The flow separation on a swept-back wing with 44 degrees leading edge sweep at 18 degrees incidence has been investigated by means of detailed pressure distribution measurements over the leading edge, boundary layer flow determination with liquid film technique, and yawmeter traverses. A wool-tuft grid was also used, and a spin detector was developed to search for regions of vorticity. These tests established that the flow separates on the leading edge; over the inboard sections it re-attaches behind a "short" separation bubble, while outboard it only re-attaches near the trailing edge, thus forming a "long" separation bubble, or else fails to attach. The separated flow in what has been commonly called the tip stall does in fact take the form of a "ram's horn" vortex with the origin, or "tip," located at the junction of the two bubbles on the leading edge. The vortex lies outwards across the wing surface at approximately 20 to 25 degrees to the line-of-flight before curving aft to be shed into the wake, where it extends almost from mid semi-span to the wing tip. This vortex induces considerable changes in flow direction, both on and over the wing, and also in the wake. Thus in the wake a maximum downwash of 23 degrees is induced aft of the mid semi-span, and there is an upwash of 17 degrees at the outer edge of the vortex, almost aft of the tip. A good correlation between yawmeter results and the boundary layer flow direction indications from the liquid film technique was obtained.

1. Introduction

The stalling of certain aerofoil sections which follows flow separation from the leading edge was commented on by Jones[1] in 1934; it is only in recent years, however, with the adoption of thinner sections and smaller nose radii for high speed aerofoils, that this type of stalling has become of great practical importance[2, 3].

When such sections are used on a swept-back wing, the tip sections stall first, at a moderate incidence. As incidence increases, the stall spreads inboard, but even up to incidences of 25-30 degrees the root sections can remain unstalled. This regime, with the co-existence of separated and attached flow regions, has associated with it a complex boundary layer behaviour and the generation of part-span vortices[4, 5].

Previous pressure distribution tests on a swept-back wing[4] suggested that the stalling of the tip sections arose from the chordwise growth of a separation bubble at the leading edge: the unstalled sections inboard retained large peak suctions almost on the leading edge. Localised constant pressure regions there indicated the existence of short separation bubbles, with re-attachment farther aft. From liquid-film studies it appeared that the boundary layer on the upper surface flowed outwards under the rear regions of the attached flow, and then swung forwards towards the leading edge under the separated flow. It was not established, however, whether the liquid-film pattern necessarily gave a true picture of the direction of flow in the boundary layer.

The aim of the present tests was to confirm the surmises about the boundary layer behaviour by direct yawmeter measurements close to the surface. It was hoped that similar measurements above the surface, and visual examination, would reveal the existence of a part-span vortex sheet, generated at the boundary between the attached and separated flows. The shedding of such a vortex also made wake investigations of interest.

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2. The Model and Apparatus

2.1. THE MODEL

The wing tested was a port semi-span model with 44° leading edge sweepback, aspect ratio 4·3 and taper ratio 0·326, and a mean chord of 10 in. (Fig. 1). The elliptic-nose aerofoil had a maximum thickness of 10 per cent. at 40 per cent. chord. Full details are given in Ref. 4.

Numerous pressure holes were drilled over the leading edge of the model in the regions where separation was known to occur. Nine holes were distributed chordwise from the leading edge to $0{\cdot}2c$ at each of a number of spanwise stations from 0·2 to $0{\cdot}68s$, where s is the span of the half-model, and c is the local chord.

2.2. THE YAWMETERS

For the boundary layer surveys over the wing surface, where only the flow directions parallel to the surface were to be measured, an arrowhead yawmeter was used[4]. The head consisted of two stainless steel hypodermic tubes, of 1 mm. outside diameter, soldered together lengthwise, with the open ends ground off at an angle of 45°. In the wake surveys, both inflow and outflow and upwash and downwash were required: a conventional four-tube claw-type yawmeter was therefore used.

Either yawmeter head could be mounted in the end of a tubular boom, which was carried in a special micrometer mounting. The heads could, by this means, be located accurately anywhere in the flow field about the model.

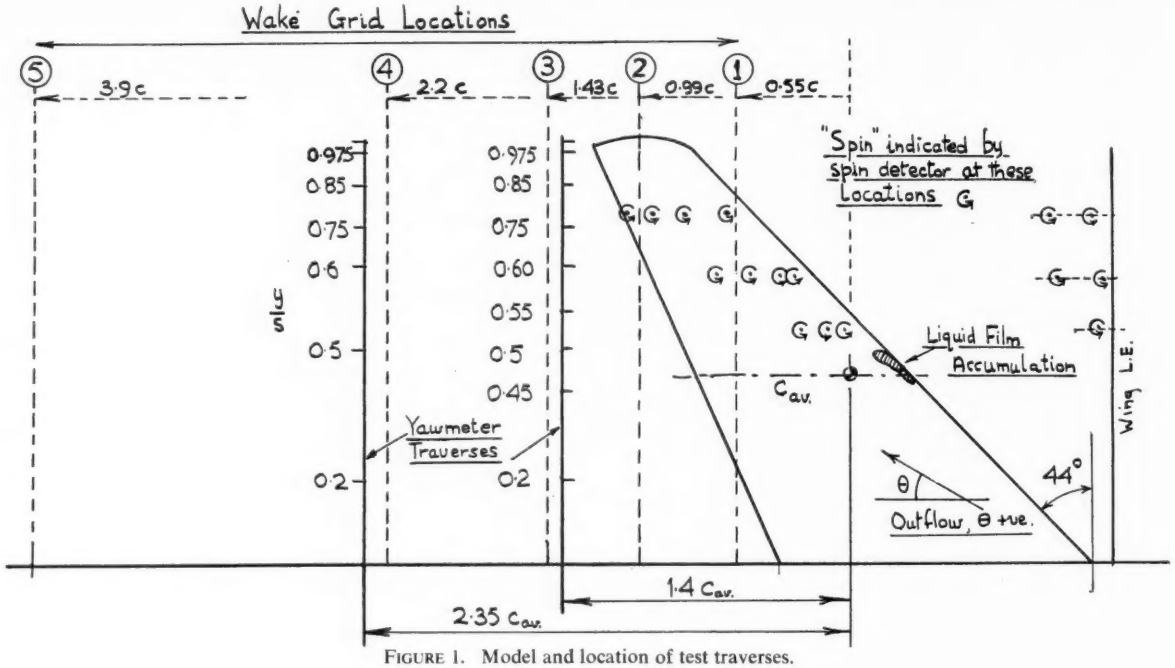


FIGURE 1. Model and location of test traverses.

2.3. THE TUFT GRID

For visual study of the flow a tuft grid was used[6]. A parallel set of fine wires was stretched, at $1\frac{1}{2}$ in. pitch, across a $2\frac{1}{2}$ ft. square metal frame. Wool tufts, 3 in. long, were attached to the wires at intervals of $1\frac{1}{2}$ in. by short lengths of fine thread, which allowed them to stream freely in any direction. After some preliminary tests, additional wires were stretched across regions of interest at $\frac{3}{4}$ in. pitch.

The grid was mounted normal to the wind at various streamwise locations (Fig. 1). The tufts were photographed with a camera mounted as far downstream as possible, to reduce parallax effects.

2.4. THE "SPIN" INDICATOR

A small flat plate aerofoil, $\frac{1}{8}$ in. chord and $\frac{3}{4}$ in. span, made of Perspex, was pivoted for rolling at zero incidence on a wire rod, so that it was free to rotate about its mid-chord. The wire rod was carried by the yawmeter boom, which allowed for any desired alignment of the "aerofoil" to the wind at any accurately determined location in the flow field.

When in a steady irrotational air stream, any initial rotation of the "aerofoil" was heavily damped: but any vorticity in the flow, for example in the core of a wing tip vortex, made it spin rapidly with a distinctive hum. Thus by traversing the spin indicator slowly across the flow, the boundaries of the regions of vorticity could be detected quite accurately and with good repeatability.

3. Details of Tests

The tests were carried out in an open-jet wind tunnel at a wind speed of 103 ft./sec., giving a Reynolds number based on the wing mean chord (10 in.) of $0{\cdot}5 \times 10^6$. Incidence was fixed at 18°, at which the overall normal force coefficient, C_n, was 0·826.

3.1. PRESSURE DISTRIBUTIONS

The pressure distributions over the whole surface had already been measured, as described in Ref. 4 (Fig. 2). More detailed measurements were made close to the leading edge, and additional holes were drilled where necessary to find the exact location of pressure peaks (Fig. 3).

3.2. SURFACE FLOW

In order to provide some indication of the likely directions of flow in the boundary layer close to the surface, a liquid film pattern was first obtained, with the model mounted vertically, tip uppermost. A suspension of finely divided titanium oxide in paraffin, with a small addition of oleic acid* as a dispersion agent, was brushed uniformly over the upper wing surface with the wind off; the wind was then rapidly brought up to the set speed. The liquid film moved over the wing surface and dried after a few minutes, leaving a white lace-like pattern in which the directions of flow were clearly discernible (Fig. 4).

The influence of gravity on the movement of the liquid film was studied by repeating the test with the model mounted vertically, tip downwards, and also with it mounted horizontally.

*The use of this white powder and oleic acid as an improvement on the lampblack previously used by the author[7] was suggested by the Chemistry Department, Royal Aircraft Establishment.

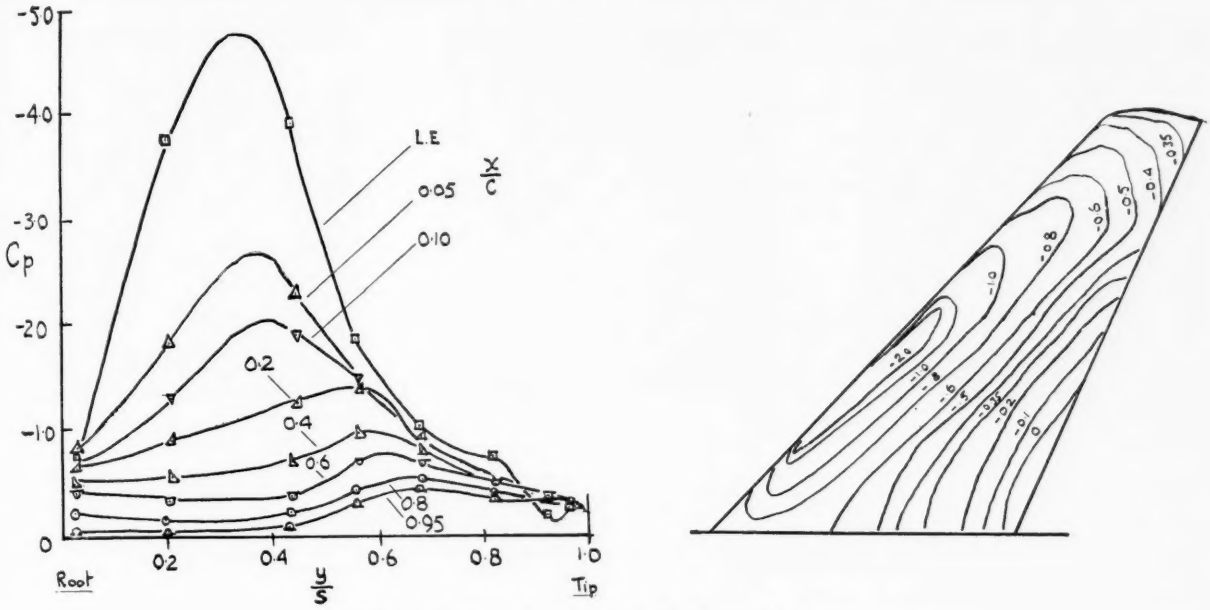


FIGURE 2. Spanwise pressure distributions and isobars.

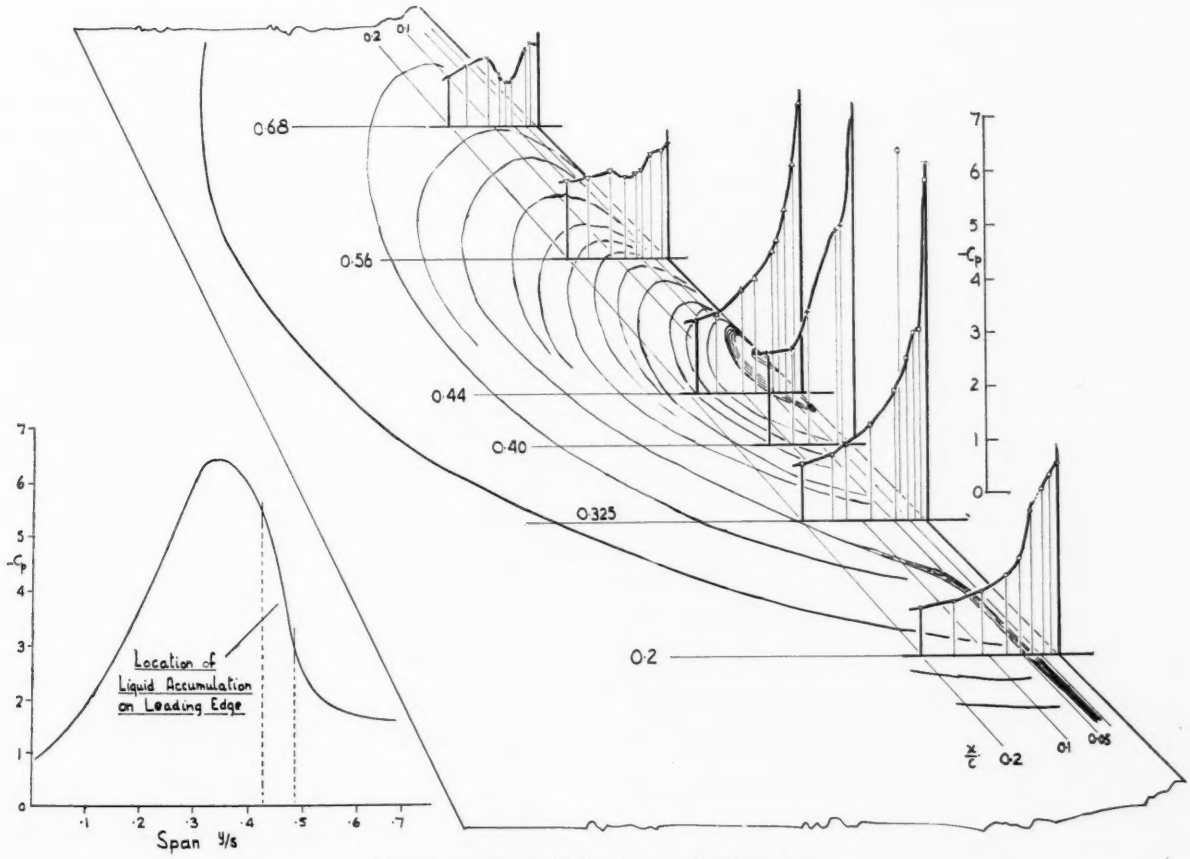


FIGURE 3. Pressure distributions over leading edge.

(*a*) Model vertical tip upwards. (*b*) Model vertical tip downwards. (*c*) Model horizontal.

FIGURE 4. Liquid film patterns of boundary layer flow.

The arrowhead yawmeter was used first to measure total head, dynamic pressure and flow direction at the trailing edge at 0·44*s* and 0·75*s* (Fig. 5). Over the wing surface, only the flow directions were measured, as the deduction of total head and dynamic pressure from arrowhead yawmeter measurements is rather lengthy; the locations of the measuring positions on the surface itself are indicated in Fig. 6.

Traverses through the boundary layer and out into the separated flow were made at selected chordwise stations at spanwise locations from 0·56*s* to 0·93*s* (Fig. 7).

As a basis for comparison for the relative amounts of inflow and outflow produced by the part-span vortex, yawmeter measurements were made across a normal wing-tip lifting vortex at a wing incidence of 9° corresponding to a C_n of 0·45 (Fig. 9).

For flow visualisation above the wing the tuft grid was mounted normal to the stream at 0·55 and 0·99 mean chord aft of the mean quarter-chord (Fig. 1); the wires were arranged so that the model could project through the grid. As a check on the influence of the model on the tufts, photographs of the grid were taken with the wing at zero incidence for each grid location, as well as at 18° incidence.

The "spin" indicator was traversed through the regions where yawmeter measurements and liquid film patterns suggested the formation of a vortex, and the distances from the wing surface at which spin started and stopped were measured.

3.3. WAKE SURVEYS

Tuft grid surveys of the wake were made first to indicate the most significant regions for yawmeter traverses. The grid was moved from just aft of the wing to almost four chords downstream (Figs. 1 and 10).

The double-claw yawmeter was traversed along the lateral axis at distances of 1·4 and 2·35 mean chord aft of the mean quarter-chord. Because the trailing edge of the wing is swept back, it does not lie normal to the plane of symmetry when the wing is at incidence; a traverse axis normal to this plane, which intersected the trailing edge at 0·7*s*, was selected. Thus inboard of this spanwise position the trailing edge lies above the lateral axis, and outboard it is below. The location of the trailing edge is marked in Fig. 12.

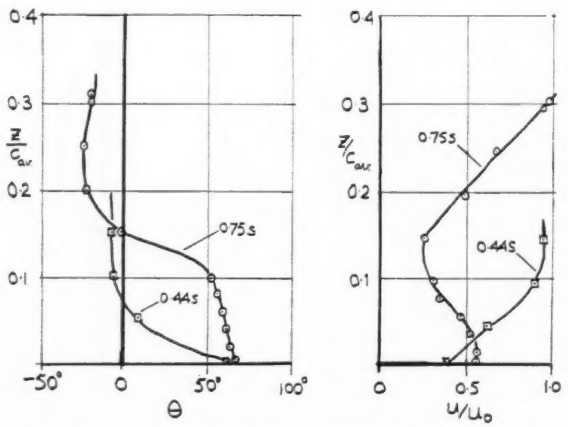


FIGURE 5. Boundary layer measurements at trailing edge.

4. Discussion of Results

4.1. FLOW CLOSE TO SURFACE

4.1.1. *Pressure Distribution*

The pressure distribution over the surface (Fig. 2, taken from Ref. 4) shows that there is a rise in suction, starting about 0·4*s* on the leading edge and successively moving farther outboard with movement aft, until at the trailing edge it occurs about 0·7*s*.

Figure 3 shows the chordwise pressure distributions over the nose obtained with the much more closely spaced holes of this test; from these a more accurate curve for the spanwise pressure distribution along the leading edge has been drawn. The sections from 0·2*s* to 0·44*s* all exhibit the typical highly localised peak suctions almost on the nose, and the discontinuities in the curves indicate the existence of short separation bubbles.

Because of flow separation the sections farther outboard have lost their peak suctions, and in addition they exhibit the unusual feature of a "trough" of small pressure recovery between 0·05*c* and 0·10*c*.

It will be seen from the spanwise distribution along the leading edge that the division between the attached and separated flows is marked by an abrupt pressure gradient; the pressure rises from a negative pressure coefficient of over 6 to 2 between 0·4*s* and 0·5*s*.

4.1.2. *Liquid Film Patterns*

The liquid film patterns in Fig. 4 all have certain features in common, irrespective of the vertical or horizontal mounting of the model. (It should be remembered that the interpretation of liquid film patterns is considerably aided by watching the actual movement of the liquid while the wind is on; only the final dried patterns are shown here.)

The nose of the inboard sections was rapidly cleared of liquid back to about 0·025*c*, where a narrow band lying parallel to the leading edge accumulated, extending from the root to about 0·3*s*. Aft of this band there was a broad outward sweep of fluid, which in the particular case with the tip vertically upward (Fig. 4(*a*)) coalesced into a distinct "stream" flowing parallel and close to the trailing edge. Beyond the mid semi-span the liquid moved forward, and then close to the leading edge turned abruptly to flow inward under the separated air, almost along the leading edge itself.

This inward flow ended in an accumulation of surplus liquid right on the leading edge about 0·44*s*; the accumulation rotated strongly in a clockwise manner (as viewed in the photograph) in the nature of a whirlpool. This was incorrectly described by the author in Ref. 4 as the possible location of a "standing" vortex. It seems correct now to assume that the rotation arises from the relative effects of gravity, pressure and tractive forces on the mass of surplus liquid (discussed later), and that there is no corresponding phenomenon in the air flow. Nevertheless, the accumulation is valuable, in that it marks the division between the attached and separated flows on the leading edge, as may be clearly seen from Fig. 3, where the "whirlpool" lies exactly within the limits of the steep adverse pressure gradient.

A significant feature of the flow over the wing was observed as the wind streamed over the wet film; a "shimmering," as though waves of very small amplitude were passing over the surface, could be seen in a triangular region lying obliquely to the free stream with its vertex on the leading edge about mid semi-span. Some trace of this effect can still be detected in the final dried patterns; in Fig. 4(*a*) as a "whitish" region, the inboard edge of which is inclined outwards at about 15°, and in Fig. 4(*b*) as a waviness in the pattern close to the dried whirlpool.

4.1.3. *Yawmeter Results*

The vector pattern from the yawmeter measurements close to the surface in Fig. 6(*a*) agrees very well with the flow directions indicated by the liquid film and justifies the use of the liquid film technique for the rapid determination of boundary layer flow.

Curves of flow direction against chordwise position are plotted in Fig. 6(*b*). In the attached flow region at 0·2*s* the flow direction changes smoothly from inflow to outflow going from leading to trailing edge. At 0·44*s* and farther outboard, however, there is a sharp rise and fall of outflow within the leading 20 per cent. of the chord, followed by a further increase of outflow. From Fig. 3 it will be seen that the inflections in the curves are located just outboard of the whirlpool and lie in the neighbourhood of the triangular region commented on before.

4.2. FLOW ABOVE THE WING SURFACE

4.2.1. *Flow Directions*

Traverses normal to the surface of swept wings have already been made[4, 8, 9] but none of these went through the separated region over the wing. Fig. 5 shows the results obtained in this test at the trailing edge at 0·44*s* and 0·75*s*. The effect of separation on the shape of the flow direction curve is marked; because of this, traverses in depth were made farther forward.

Figure 7 shows the flow directions at selected chordwise stations up to a height of 0·3c_{av} (an actual height of 3 in. since the average chord of the model was 10 in.) at the spanwise locations of interest. The curves for spanwise sections inboard of 0·56*s* had the same shape.

Near the leading edge at 0·63*s* a "vortex" type of flow direction curve first appears, with an inflow on the surface of over 150° changing to 60° outflow, and then with increasing distance from the surface reducing to about 10°. All the curves farther outboard show this feature, a particularly striking change being at 0·1*c* at 0·75*s*, with 250° of flow direction alteration at about 0·03*c* above the surface. The change in flow direction may be visualised more easily from Fig. 8, where the

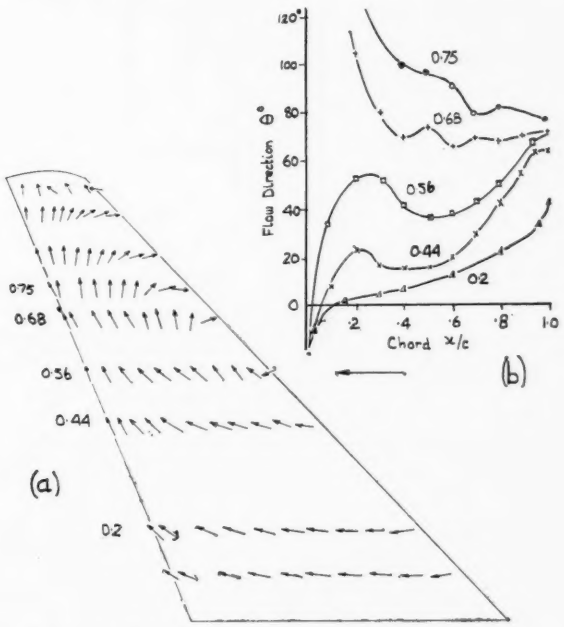


FIGURE 6. Yawmeter measurements of flow on the surface.

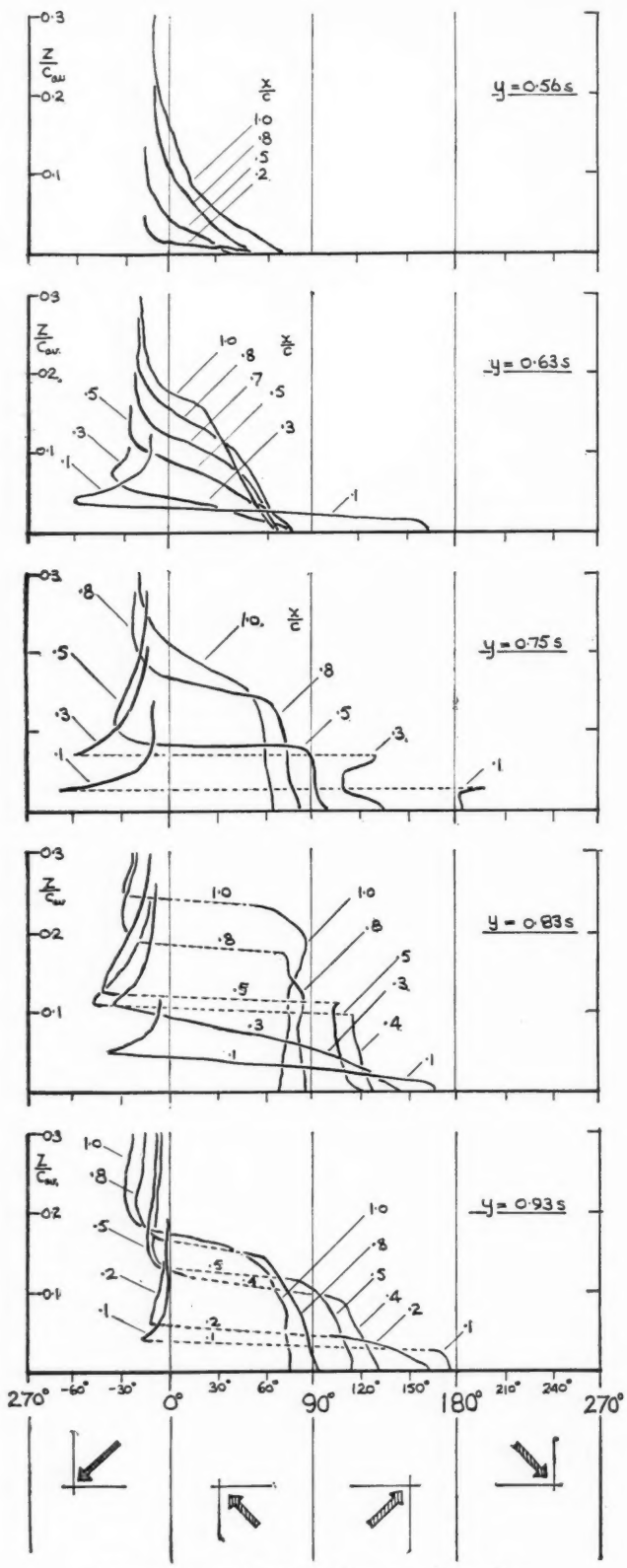


FIGURE 7. Flow directions above the wing surface.

flow on the surface and the maximum inflow are drawn vectorially.

The results of a similar traverse across a wing tip lifting vortex at an incidence of 9° are shown in Fig. 9; apart from the smaller range of direction change, the wing tip vortex is much deeper vertically than that over the nose in Fig. 7. This contrast presumably arises because the wing tip vortex is fully developed with a circular cross-section, whereas the traverse going from the main flow over the wing into the separated flow passes through the thin vortex sheet dividing the two flows; this sheet will produce a large change in direction in a relatively small distance, giving the "flattened" curves already described.

The height of the maximum inflow at each chordwise station was taken as an indication of the location of the vortex sheet. These heights are plotted along the chord for the various spanwise stations in Fig. 11. It would appear that the flow over the outer sections separates at the leading edge and moves away from the surface as it travels aft, until over the trailing edge it is between 0·1 to 0·2c_{av} above it.

4.2.2. *Tuft Grid Indications*

Photographs of the behaviour of the tufts with the grid at 0·55c and 0·99c, both with the wing at zero incidence and at 18°, are shown in Figs. 10(*a*), (*b*) and (*c*). The strong clockwise rotation of flow (looking upstream) centred about mid semi-span can be clearly seen, with the outward flow along the surface and the marked inflow even some distance above the wing.

4.2.3. *Detection of Spin Regions*

It was found that the "spinner" spun rapidly in regions outboard of mid semi-span. The locations of these regions, at 0·68s and 0·83s, are plotted in Fig. 11, for comparison with the height of maximum inflow.

The agreement is quite good and does suggest that for a rapid determination of the existence of vortex flow in the separated region the spin indicator is valuable.

4.3. FLOW IN THE WAKE

4.3.1. *Yawmeter Traverses*

Some of the flow directions measured at distances 1·4c_{av} and 2·35c_{av} aft of the mean quarter-chord can be seen in Fig. 12.

At 0·2s, which is aft of the attached flow, there is an almost constant inflow of 5° from 0·3c_{av} above to 0·2c_{av} below the traverse axis (Fig. 12(*a*)). Farther outboard at 0·55s the inflow at 0·3c has increased to 10°, but there is slight outflow on the axis. At 0·75s this change-over becomes appreciable, and the inflow-outflow curve is of the "vortex" type; maximum inflow is 24° and maximum outflow 10°. The "centre" of this curve is located 0·15c_{av} above the axis, which at this spanwise position is almost coincident with the trailing edge.

The cross-plotted curves for flow direction along the span at two heights, 0·1 and 0·3c_{av} above the axis, in Fig. 12(*b*) show that maximum inflow occurs between 0·7s and 0·8s at the higher level, while lower down, on the axis, there is outflow from mid semi-span to the tip.

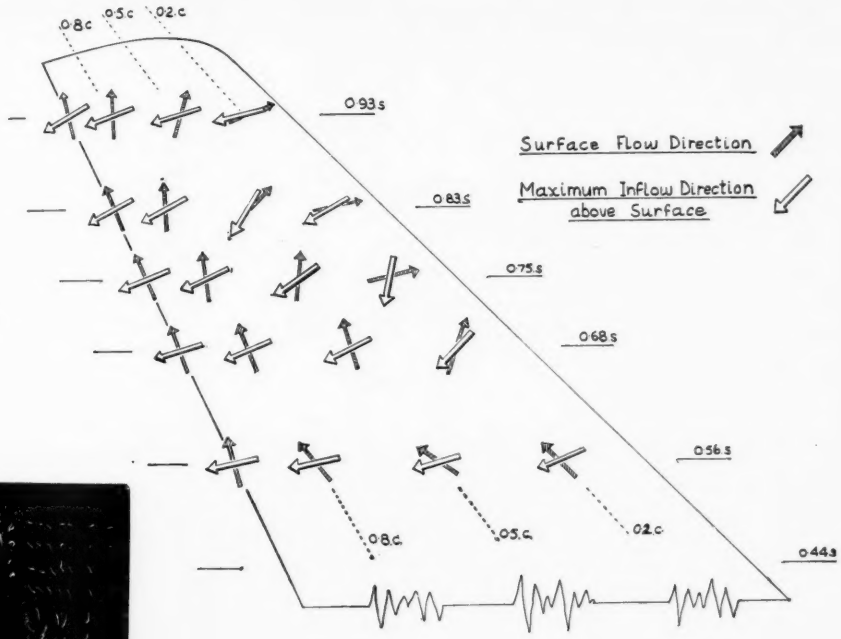
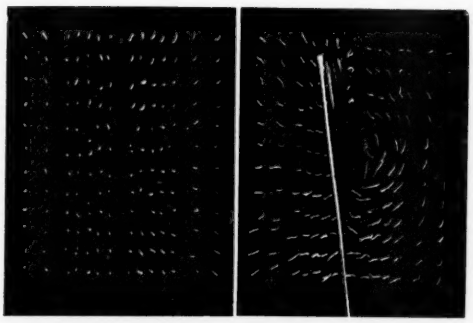
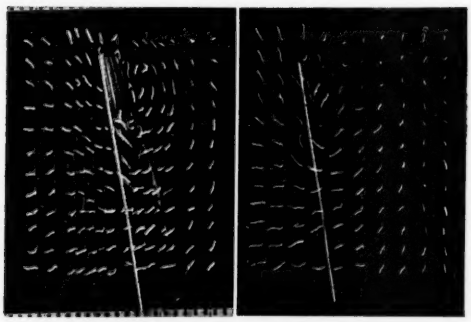


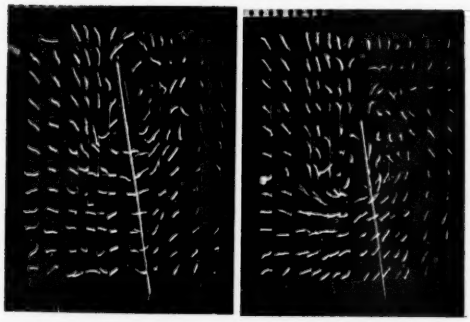
FIGURE 8. Maximum inflow over the wing.



(*a*) Zero incidence (*b*) $0{\cdot}55c_{av}$



(*c*) $0{\cdot}99c_{av}$ (*d*) $1{\cdot}43c_{av}$



(*e*) $2{\cdot}2c_{av}$ (*f*) $3{\cdot}2c_{av}$

FIGURE 10. Photographs of tuft grid as it is moved downstream. Incidence 18 degrees.

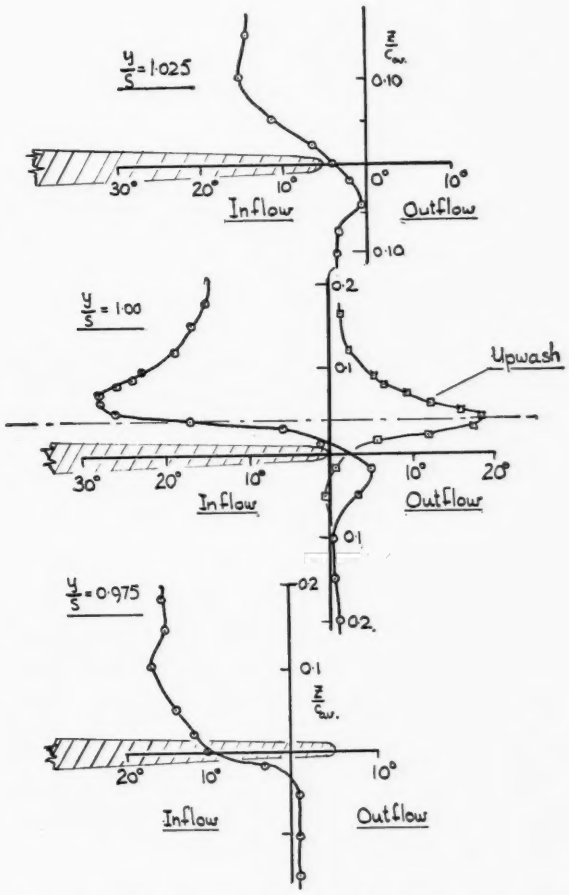


FIGURE 9. Flow directions in a wing tip lifting vortex at 9° incidence ($C_n = 0{\cdot}45$).

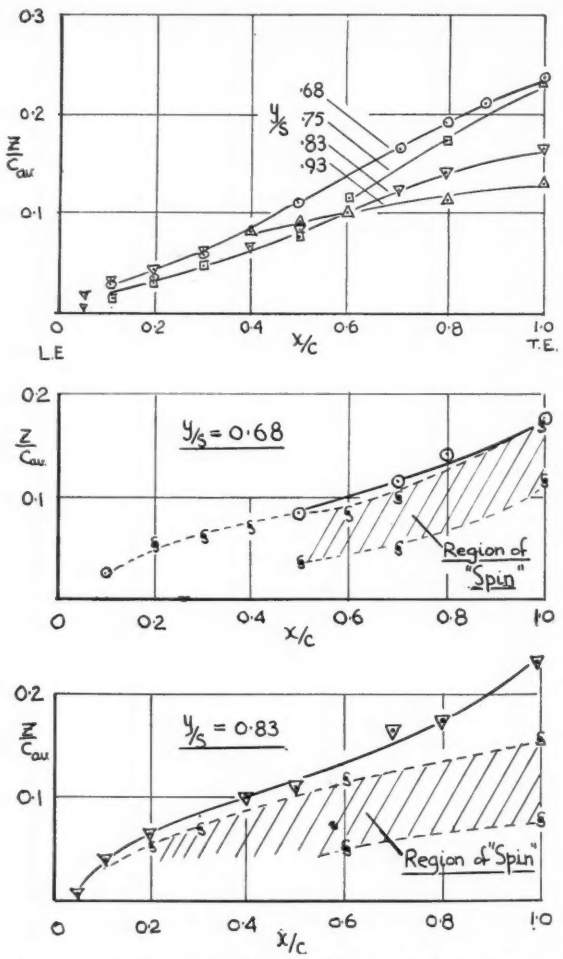


FIGURE 11. Location of maximum inflow and regions of "spin."

The distributions normal to the wing axis of upwash and downwash, and also the flow direction changes along the span at a height of $0{\cdot}1c_{av}$ above the axis, are shown in Fig. 12(*c*) and (*d*). Again "vortex" type curves are obtained outboard; the spanwise curve in Fig. 12(*d*) indicates a maximum downwash of 23° at $0{\cdot}53s$, zero downwash at $0{\cdot}63s$, and a maximum upwash of 16° at $0{\cdot}73s$.

The dotted curve in the same figure shows that the "vortex" flow is still appreciable farther aft at $2{\cdot}35c_{av}$, with 20° of downwash and 10° of upwash. There is a slight outward drift of the vortex with movement aft.

In flow visualisation tests on a geometrically similar wing in a water tunnel, Lambourne and Pusey[10] produced photographs showing a strong downwash in the wake about mid semi-span, corresponding to the 23° of downwash at $0{\cdot}53s$ in Fig. 12(*d*).

They also attempted to study the flow in the separated region over the wing surface by introducing a thin stream of air bubbles just ahead of the wing leading edge. These bubbles revealed a spiralling motion in the flow over the outer section of the wing, in agreement with the tuft grid behaviour described earlier in Section 4.2.2. In addition, a thin "streak" of aeration extending downstream into the wake from the trailing edge at the inner boundary of the separated region was clearly visible in the photographs. This was described by Lambourne and Pusey as the trail of a discrete vortex being shed at this point, which they felt might be a manifestation of the part-span vortex suggested by Kuchemann[5].

The results of the present tests in air flow, showing continuous distribution of vorticity from the downwash at $0{\cdot}5s$ to the upwash at $0{\cdot}8s$, do not confirm the existence of such a discrete vortex.

Explorations immediately behind the trailing edge in the wind tunnel tests showed that vorticity is being shed all along the span right from the root out to the inner limit of the separated region. This vorticity arises from the difference in flow directions where the boundary layers of the two *attached* air streams coming over the upper and lower surfaces meet just aft of the trailing edge; consequently it should be strongest about mid semi-span where there is strong outflow over the upper surface at the trailing edge, while the flow over the lower surface is almost along the free stream direction. Thus a vortex rotating in an anti-clockwise direction (looking upstream) could be shed from the trailing edge, whereas the rotation in the separation region is clockwise.

The "streak" in the water tests may arise from the entrainment of some air in this shed vortex, and if this is so, its only significance is that it denotes the outer limit of attached flow. It should not be thought of as a part-span vortex, however, in that it originates from attached flows at the trailing edge, in contrast to the generally accepted idea that a part-span vortex arises from separation effects at the leading edge.

4.3.2. *Tuft Grid in the Wake*

The rotation in the wake shows up clearly in the tuft grid photographs in Figs. 10(*d*), (*e*) and (*f*). These confirm the yawmeter measurements, especially the fact that the vortex shed from the wing extends from almost mid semi-span out to the tip.

4.4. THE "RAM'S HORN" VORTEX

The flow mechanism which emerges from all the evidence presented appears to be as follows.

The flow over the root sections separates at the leading edge and re-attaches farther aft behind a short separation bubble. Farther outboard the separated flow just re-attaches near the trailing edge, and there is a long separation bubble: photographs in the water tunnel tests[10] confirm this. The pressure difference at the common boundary of the two bubbles must be sustained by a curved vortex sheet, generated almost on the leading edge itself, since that is where the bubbles are located.

The vortex sheet at this stage of its development lies obliquely to the free stream. The measurements with this particular plan form suggest that the origin of the vortex is at $0{\cdot}44s$ almost on the leading edge and that its axis lies at approximately 20° to 25° outwards from the free stream direction.

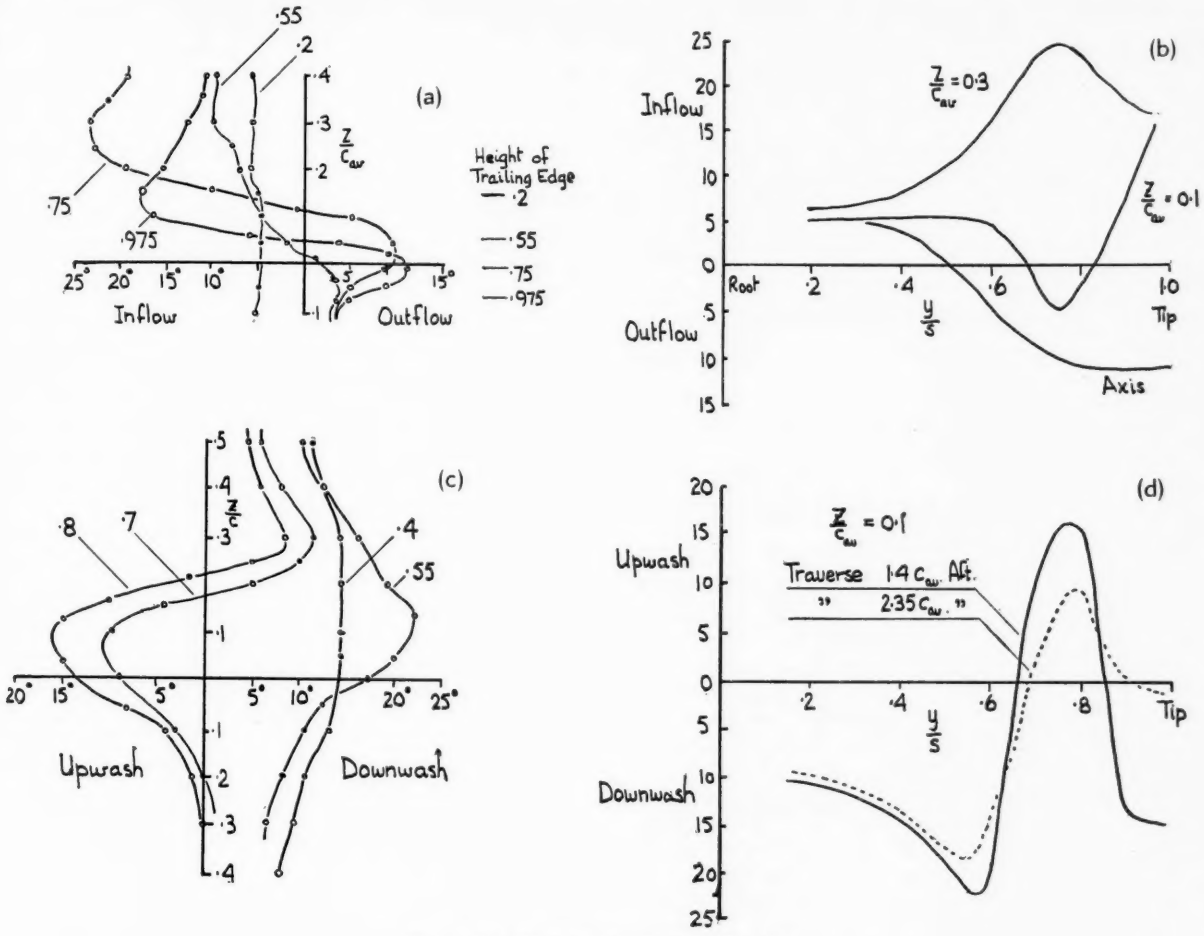


FIGURE 12. Yawmeter traverses in the wake.

As the vortex develops it widens considerably and swings aft to lie almost along the free stream. The axis of the vortex, which tends to follow the free stream, leaves the surface about mid-chord, owing to the high incidence of the wing. Thus where the vortex passes over the wing trailing edge its axis is between 0·1 to 0·2c_{av} above it. In shape the fully developed vortex resembles the curved form of a ram's horn (Fig. 13) with the tip lying on the leading edge.

The presence of this vortex accounts for the increases in suction noted over the rear outer region of the wing, the abrupt flow direction changes both on the surface and above, the rotation of the spin indicator, the alignment of the tufts both in earlier surface tests and in these grid tests, and the behaviour of the liquid film.

The explanation of the rotating accumulation of liquid on the leading edge (also obtained in the water tunnel tests using machine oil) is now clear, and disposes of the erroneous suggestion by the author in an earlier paper that the rotation arose from a standing vortex.

Where the ram's horn vortex sweeps the surface over the outer wing it induces the liquid, flowing outwards to the tip from the attached flow inboard, to turn and flow towards the leading edge (Fig. 13). The liquid thus swept forward almost to the leading edge collects at the forward limit of separated flow (about 0·1c in Fig. 3, and very clearly delineated by the sharp inward turn of the " rivulets " in Fig. 4(*c*)). Here it comes under the influence of the strong pressure gradient along the leading edge, which causes it to flow inwards until finally it collects at the outer limit of attached flow. Even with the wing mounted vertically, tip downwards, the pressure gradient can draw the surplus liquid inboard (that is, vertically upwards) in the separated flow region where the tractive forces from a moving air stream are negligible.

In the region on the leading edge where the surplus liquid meets the attached flow near the point of maximum suction, the tractive force turns it sharply aft in a chordwise direction. This brings the liquid back under the vortex tip again, which induces it to flow towards the leading edge. The accumulated liquid thus rotates in this localised region under the three distinct influences of the attached flow inboard, the induced flow from the vortex, and the pressure force arising from the peak suction of the attached flow.

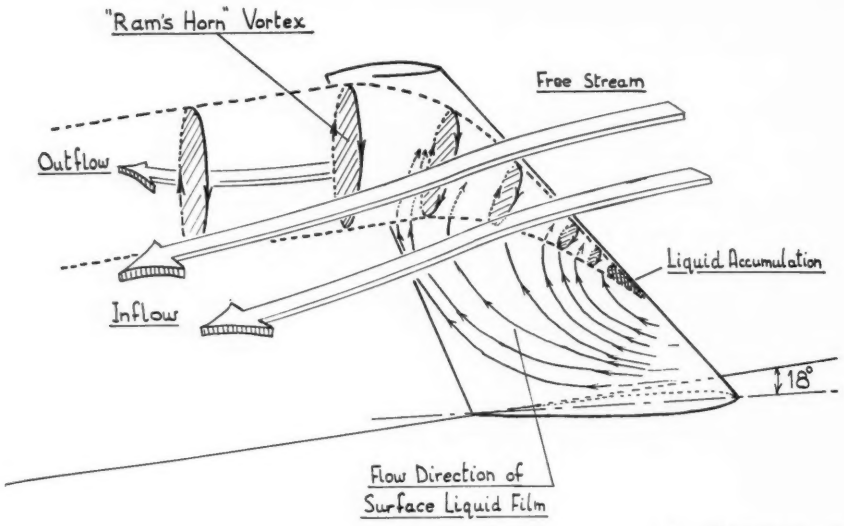


FIGURE 13. The "ram's horn" vortex emanating from the leading edge.

4.5. SCALE EFFECT

The Reynolds number of these tests ($0{\cdot}5 \times 10^6$) is very low, and the actual onset of separation indicated on the model may not agree well with that occurring at higher Reynolds numbers. Nevertheless, aerofoil tests have established that the class of aerofoil used on this wing always stalls following separation from the leading edge and that separation bubbles are formed, over a wide range of Reynolds number. We can at least be tolerably certain, therefore, that the mode of separation has been correctly demonstrated.

Once separation has occurred the flow behaviour should be comparatively independent of Reynolds number, and even on a full-scale wing the formation of a "ram's horn" vortex can be anticipated. The actual location of the vortex tip on the leading edge is likely to be the flow feature most seriously affected by scale effect.

On the other hand, compressibility is likely to have a marked effect, since the pressure distributions round the wing may be appreciably altered; the location and form of the separation vortex at high Mach numbers cannot easily be predicted from these tests.

Conclusions

1. The flow in the separation region over the outer span of the wing has been shown to take the form of a "ram's horn" vortex originating from the junction on the leading edge of the inboard "short" separation bubble and the outboard "long" separation bubble. Large changes in flow direction, both over the wing surface and in the wake, are induced by this vortex; for example, the boundary layer on the upper surface is turned through over 120° so that it flows forward towards the leading edge under the vortex, while inflows of over 60° have been measured in the same region above the vortex.

The vortex shed into the wake extends almost from mid semi-span to the tip; it induces a maximum downwash aft of the mid semi-span of 23°, and the upwash at the outer limit of the vortex, aft of the tip, is about 17°.

2. The pattern produced on the wing surface by the liquid film technique is an accurate indication of the direction of flow of the attached boundary layer, but in regions of separated flow the liquid tends to follow the pressure gradient. Rotation of an accumulation of liquid occurs at a junction between attached and separated flows.

3. Yawmeter measurements of the flow past particular plan form wings can be very time-consuming, but liquid film tests, spin-detector traverses, and tuft grid photographs take comparatively little time and effort. It is hoped that the results in this paper have demonstrated that much information about the separation phenomena can be obtained by these simple means.

ACKNOWLEDGMENTS

Some of the experiments described were carried out by J. F. Sharpe, B.Sc. and J. Walters, B.Sc. as an investigation in part fulfilment of the requirements for an Honours degree in Engineering in the University of Bristol.

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TECHNICAL NOTES

Contributions to this Section of the JOURNAL *will be eligible for Journal Premium Awards and will normally be published within two months of being received.*

Note on the Numerical Evaluation of the Wave Drag of Smooth Slender Bodies Using Optimum Area Distributions for Minimum Wave Drag

by

E. EMINTON AND W. T. LORD

(Royal Aircraft Establishment)

THE LINEARISED theory value of the wave drag D at zero lift of a smooth slender body of arbitrary cross-sectional shape was shown by Ward[1] to be given by

$$\frac{D}{q} = \mathrm{I} \equiv -\frac{1}{2\pi}\int_0^1\int_0^1 S''(x)\,S''(y)\log|x-y|\,dxdy,$$

where $S(x)$, $0 \leqslant x \leqslant 1$, is the cross-sectional area distribution of the body and q is the kinetic pressure. The development of this result has aroused interest in two problems: the derivation of the optimum area distribution for minimum wave drag under certain specified conditions and the numerical evaluation of the wave drag of a specified area distribution. These apparently distinct problems have hitherto been treated separately, but it is shown here how an attempt to solve the first problem has led to a practical method of solving the second*.

The theory requires the area distribution to be smooth so that $S'(x)$ is a continuous function of x with $S'(0)=S'(1)=0$. It may therefore be expressed by the transformation

$$x=\tfrac{1}{2}(1-\cos\theta),$$

as a function of θ for $0 \leqslant \theta \leqslant \pi$ which has a convergent Fourier sine series

$$S'(x)=\sum_{r=1}^{\infty} a_r \sin r\theta, \qquad 0 \leqslant x \leqslant 1,$$

where

$$a_r=\frac{2}{\pi}\int_0^{\pi} S'(x)\sin r\theta\, d\theta, \qquad r \geqslant 1.$$

This expression may be integrated directly to give $S(x)$ in terms of θ and the coefficients a_r:

$$S(x)=S(0)+\tfrac{1}{4}a_1\theta+\tfrac{1}{4}\sum_{r=1}^{\infty}\frac{1}{r}(a_{r+1}-a_{r-1})\sin r\theta.$$

It may also be substituted in the integral I which, on integration by parts, gives I in terms of the coefficients a_r:

$$\mathrm{I}=\frac{\pi}{4}\sum_{r=1}^{\infty} r a_r^2.$$

These expressions may be used to derive area distributions which minimise the integral I under certain specified conditions. We simply require the values of the coefficients which make I a minimum subject to the conditions on $S(x)$ which relate them. This is often a straightforward application of the theory of maxima and minima, for if the conditions on $S(x)$ can be written $\xi_i\{S(x)\}=0$, $i=1, 2 \ldots$, then a necessary condition for I to be a minimum subject to $\xi_i=0$, $i=1, 2 \ldots$, is

$$\frac{\partial D/q}{\partial a_r}+\Sigma\lambda_i\frac{\partial \xi_i}{\partial a_r}=0$$

for each a_r and some constants λ_i, $i=1, 2 \ldots$. If the values of a_r which satisfy this necessary condition yield convergent series for $S(x)$ and I, then these give the required area distribution and the corresponding minimum value of the integral for the specified conditions.

When the specified conditions define the nose area $S(0)=N$, base area $S(1)=B$ and n intermediate areas $S(k_i)=A_i$, $i=1, 2, \ldots, n$, this technique produces the result

$$S(x)=N+(B-N)\,u(x)+\sum_{i=1}^{n}\lambda_i p(x,k_i),$$

$$\mathrm{I}=\frac{4}{\pi}(B-N)^2+\pi\sum_{i=1}^{n}\sum_{j=1}^{n}\lambda_i\lambda_j p(k_i,k_j),$$

where the constants λ_i, $i=1, 2, \ldots, n$, are given by the n linear equations

$$\sum_{i=1}^{n}\lambda_i p(k_i k_j)=c_j, \qquad j=1, 2, \ldots, n,$$

and the functions $u(x)$, $p(x, y)$ are defined by

$$u(x)=\frac{1}{\pi}\left[\cos^{-1}(1-2x)-2(1-2x)\sqrt{[x(1-x)]}\right],$$

$$p(x,y)=-\tfrac{1}{2}(x-y)^2\log\frac{x+y-2xy-2\sqrt{[xy(1-x)(1-y)]}}{x+y-2xy+2\sqrt{[xy(1-x)(1-y)]}}+$$
$$+2(x+y-2xy)\sqrt{[xy(1-x)(1-y)]}$$

and c_j denotes the function

$$c_j=(A_j-N)-(B-N)\,u(k_j).$$

Inspection of this result reveals that the area distribution is not slender in the sense required by the theory for, however small $S(x)$ and $S'(x)$ may be, $S''(x)$ is infinite

*Special reference must be made to the method by Routledge, Lord and Eminton[2] of evaluating the wave drag by the use of Fourier series. In its published form this method has a more restricted application than was at first supposed and has now been superseded by the method described here.

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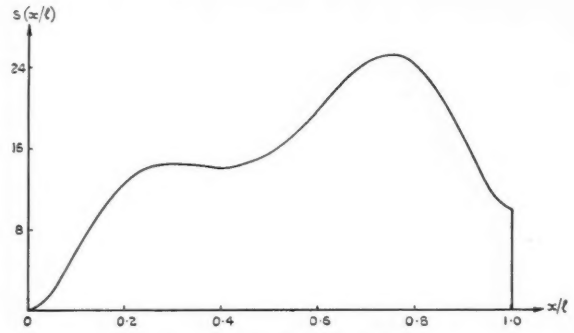

FIGURE 1. Area distribution $S(x)$.

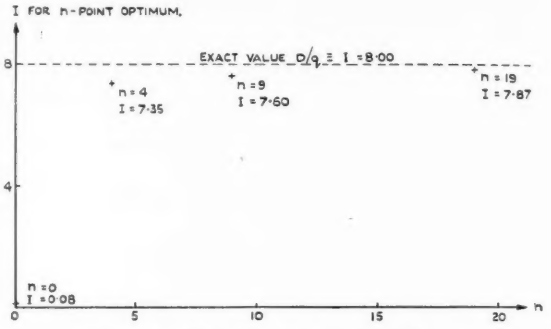

FIGURE 2. Drag D and its approximations.

at $x=0$ and 1 and at each of the points $x=k_i$. We cannot therefore, without further investigation, identify the integral I with the wave drag or the area distribution $S(x)$ with the optimum area distribution for minimum wave drag for these conditions. The result is nevertheless of immediate value for it suggests a method for the numerical evaluation of the wave drag of any smooth slender body from a graph or table of its area distribution which is well suited to an automatic digital computor but is quite simple to apply with a desk machine alone. Since the word optimum is invariably used to describe the kind of distribution with which this note is concerned we shall use it here for simplicity, since the accuracy of the description is irrelevant to the validity of this method for calculating wave drag.

If $S(x)$, $0 \leqslant x \leqslant 1$, is the area distribution of any smooth slender body and the value of $S(x)$ is known at $x=0$, $x=1$ and at n equally spaced intermediate points, the value of the integral I for the optimum through these points can then be calculated. If n is increased in such a way that each set of n points includes the previous set, the values of the integral I for the corresponding optima form a monotonic non-decreasing sequence bounded above by the value of the integral I for the given distribution. If this is the least upper bound, then by taking n large enough it should be possible in this way to calculate the slender-body approximation to the wave drag as accurately as the data allow.

The functions $u_i \equiv u(k_i)$, $p_{ij} \equiv p(k_i, k_j)$, $i, j = 1, 2, \ldots, n$, of the n equally spaced points $k_i = i/(n+1)$, $i = 1, 2, \ldots n$, may be computed for any value of n. If the matrix $[p_{ij}]$ is now inverted, the corresponding expression for the integral I simplifies further to

$$\mathrm{I} = \frac{4}{\pi}(B-N)^2 + \pi \sum_{i=1}^{n} \sum_{j=1}^{n} c_i c_j f_{ij}$$

where $$[f_{ij}] = [p_{ij}]^{-1}.$$

Once the matrix $[p_{ij}]$ has been inverted and the elements f_{ij}, $i, j = 1, 2, \ldots, n$, of its inverse have been tabulated, the calculation of the integral I for any optimum distribution with specified areas at $x=0$, $x=1$ and at n equally spaced intermediate points reduces to:

(*i*) computing the n functions

$$c_i = (A_i - N) - (B-N)\,u_i, \qquad i = 1, 2, \ldots, n,$$

(*ii*) summing the series

$$\mathrm{I} = \frac{4}{\pi}(B-N)^2 + \pi \sum_{i=1}^{n} \sum_{j=1}^{n} c_i c_j f_{ij}.$$

The first of these steps is the work of a few minutes on a desk machine; the second takes a few hours on a desk machine, but for an automatic computor such as the DEUCE at the R.A.E., it is a standard programme which takes a few minutes.

So far only bodies of unit length have been considered. This simplifies the analysis without loss of generality, since for a body of length l and area distribution $S(x/l)$, $0 \leqslant x \leqslant l$, the wave drag is given by

$$\frac{D}{q} = \frac{1}{l^2}\mathrm{I} \equiv$$

$$\equiv -\frac{1}{l^2}\frac{1}{2\pi}\int_0^1\int_0^1 S''(x/l)\,S''(y/l)\log|x/l - y/l|\,d(x/l)d(y/l),$$

where dashes denote differentiation of a function with respect to its argument.

The assumption on which the method rests—that the value of I for the given distribution, which is an upper bound of the values of I for the approximating optima, is in effect the least upper bound—remains unjustified. Even if it were rigorously established we should still have to resort to analytical examples to form some sort of estimation of the number of intermediate areas that should be taken to give a reasonable approximation. Such an example has been constructed to illustrate the method and to indicate how the accuracy of the approximation increases with that number.

The area distribution of this example is represented by a polynomial with the coefficients chosen so that $S(x/l)$ resembles the area distributions of recent high speed aircraft and satisfies the requirements of slender-body theory. The values of I for the optima with the same nose area, base area and areas at 0, 4, 9 and 19 intermediate points, dividing the length into respectively 1, 5, 10 and 20 equal intervals, have been calculated and compared with the drag of the distribution as given by the exact evaluation of the integral. The chosen example is

$$S'(x/l) = 60\,(x/l)\,(1-x/l)\,(3-10x/l)\,(4-10x/l)\,(3-4x/l)$$

so that

$$S(x/l) = 10\,(x/l)^2\,[400\,(x/l)^4 - 1{,}176\,(x/l)^3 + 1{,}257\,(x/l)^2 - 588\,(x/l) + 108]$$

and

$$\frac{D}{q} = \frac{1}{\pi l^2}\,(40{,}200).$$

If $l = 40$ ft. this area distribution in square feet is similar to that of a swept wing on a cylindrical body. The area distribution is given in Fig. 1 and the values of the integral I for the distribution and the optima which approximate to it in Fig. 2. The nine-point approximation is within

5 per cent. and the nineteen-point approximation within 2 per cent. of the analytical value of the wave drag.

This example and other test cases that have been considered indicate that a result of some significance may be expected from the nineteen-point approximation for all but the most irregular area distributions. The accuracy of the approximation depends on how well the nineteen points define the character of the distribution, which is required by the theory on which the method is founded to be both smooth and slender. Tables have been computed of the values of the functions u_i, p_{ij} and f_{ij} used in a nineteen-point approximation and these tables are published in a fuller discussion[3] of the subject.

Although the nineteen-point approximation is now in practical use at the R.A.E. the method is still under test and it may well be found desirable in the light of experience to increase the number of points. This will require initially the computation of enlarged tables and will necessarily lengthen somewhat the subsequent calculation. The possible extent of such an increase may be limited in general by the capacity of the DEUCE and for each distribution by the accuracy of the data which must define in some way the maximum number of points appropriate to it. However in order to retain the speed and simplicity which recommend this method it is advisable to keep as far below the possible maximum as is consistent with a reliable approximation.

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$$I = -\int_0^1 \int_0^1 S''(x)\, S''(\xi) \log |x-\xi|\, dx d\xi$$

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Fundamental Frequencies of Arbitrarily Shaped Simply-Supported Triangular Plates

by

BERTRAM KLEIN

(Los Angeles, California)

A SIMPLE set of curves is presented from which may be calculated the lowest natural frequency of flexural vibration of practically any triangular plate of constant thickness and with simply-supported edges. In many cases the results are self checking since the calculations usually may be carried out in three independent ways and compared.

DEVELOPMENT

In a previous paper[1] the fundamental frequencies of isosceles triangular plates of constant thickness and with simply-supported edges were calculated. Since triangular plates are seldom exactly isosceles in actual design, it is of interest to devise a method of treating non-isosceles triangular plates. A purely theoretical approach may be pursued in which skew co-ordinates are used and some numerical or analytic[2] method of analysis is employed, but the amount of work involved becomes excessive. Therefore a simple semi-empirical scheme is adopted to solve the problem as follows.

It is known from previous work[2] that the results for non-isosceles plates can be presented graphically, as shown in Fig. 1, in terms of a non-dimensional parameter, h'/a, and an angle, θ. As seen, h' is the length of a median line, a is the corresponding semi-base, and θ is the angle included between the altitude to the base and the chosen median line. Now for isosceles triangular plates, $\theta = 0$, if one chooses the base whose median line and altitude coincide. However, there is another base of the isosceles triangle for which this coincidence is not true and $\theta \neq 0$ (except in the special case of an equilateral triangle). Since the natural frequency is independent of the choice of the base and its associated values of h', a and θ, it is possible to determine values of γ in the equation for ω

$$\omega = \frac{\gamma}{(h')^2}\sqrt{\frac{gD}{q}} \quad . \quad . \quad . \quad (1)$$

(where g is gravitational acceleration, D is the plate stiffness, and q is the plate weight per length squared) for values of θ different from O by equating expressions

$$\left[\frac{\gamma}{(h')^2}\right]_\theta = \left[\frac{\gamma}{(h')^2}\right]_{\theta=0} \quad . \quad . \quad . \quad (2)$$

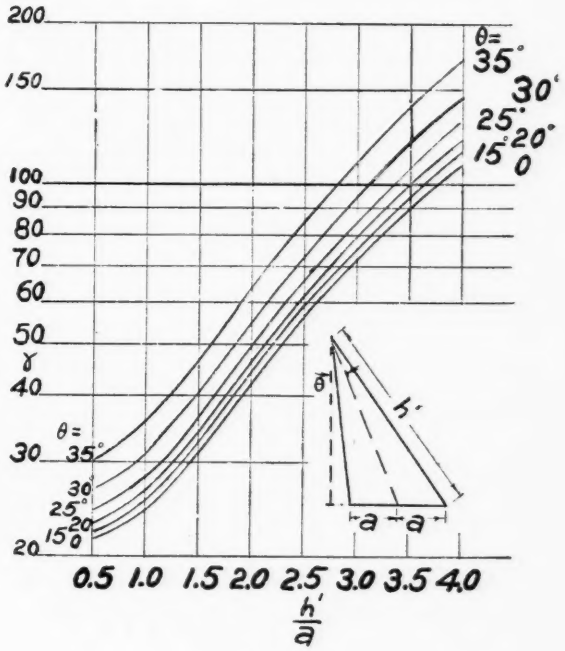

FIGURE 1.

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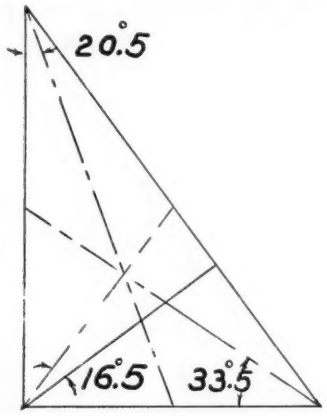

θ	h'	a	h'/a	γ	γ/h'^2
16.5	2.50	2.50	1.00	25.8	4.12
20.5	4.27	1.50	2.85	74.0	4.06
33.5	3.59	2.00	1.79	52.0	4.03

FIGURE 2.

In this way several points on the curves given in Fig. 1 have been determined for which $\theta \neq 0$.

In the general case when the triangle is non-isosceles, all three θ differ from zero and each other, and one may write:

$$\left[\frac{\gamma}{(h')^2}\right]_{\theta_1} = \left[\frac{\gamma}{(h')^2}\right]_{\theta_2} = \left[\frac{\gamma}{(h')^2}\right]_{\theta_3}. \quad . \quad (3)$$

Using such equations, and previously determined values, more points on the curves given in Fig. 1 have been established.

When the value of θ exceeds 35°, the accuracy of the method appears to begin to be affected. However, it is believed that in any triangle, at least one θ will always be less than 35°. Furthermore, it is believed that the most accurate estimate of ω is obtained when the smallest value of θ is used. Of course one should check using other values of θ for other sides of the triangle when these values are less than 35° (*see* example below).

NUMERICAL EXAMPLE

A typical non-isosceles triangular plate is shown in Fig. 2, together with the calculations for determining ω. The three results obtained using the three sets of values of θ, h' and a, and the corresponding curves in Fig. 1, are seen to differ by at most 2 per cent. Since the possible error in the curve labelled $\theta = 0$ for isosceles plates is about 2 or 3 per cent[2], the result is considered quite satisfactory.

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Derivation of the "Prandtl-Meyer" Expansion Solution from the Linear Approximation

by

J. LOCKWOOD TAYLOR

(Norges Tekniske Högskole)

EACH small stage of the expansion starts with a uniform supersonic stream and finishes with a similar stream accelerated, expanded and turned through a small angle. We are therefore justified in applying to each stage the linear (Ackeret) approximation for small departures from uniform flow, according to which

$$\delta U = \frac{U \delta \alpha}{\sqrt{(M^2 - 1)}},$$

where U = air velocity

M = Mach number

α = inclination of flow.

Also along any streamline, from the Bernoulli equation,

$$\frac{U}{M}\left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{1}{2}} \text{ is constant.}$$

Differentiating,

$$\frac{\delta U}{U} = \frac{\delta M}{M\left(1 + \frac{\gamma - 1}{2} M^2\right)}.$$

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Hence

$$\delta \alpha = \sqrt{(M^2 - 1)}\,\frac{\delta U}{U}$$

$$= \frac{\delta M \sqrt{(M^2 - 1)}}{M\left(1 + \frac{\gamma - 1}{2} M^2\right)}.$$

Integration gives

$$\alpha = \frac{1}{\lambda} \tan^{-1} \lambda \sqrt{(M^2 - 1)} - \tan^{-1} \sqrt{(M^2 - 1)}$$

where

$$\lambda = \sqrt{\left(\frac{\gamma - 1}{\gamma + 1}\right)}$$

or

$$\alpha = \theta - \mu,$$

which is easily seen to agree with the Prandtl-Meyer solution, θ being the angle of the radius vector, μ the slope of the Mach line and α the angle of deflection of the flow.

Thus although the Prandtl-Meyer expression is usually derived from the general non-linear differential equation for two-dimensional compressible flow, it can equally well be got from the much simpler linearised equation.

Note on the Minimum-Weight Design of Thin-Walled Cells in Combined Bending and Torsion

by

V. CADAMBE AND S. KRISHNAN

(National Physical Laboratory of India, New Delhi)

IN A RECENT PAPER[1] the authors suggested that the minimum weight design of thin-walled cells in combined bending and torsion could be tackled by using the well-known concept of equivalent bending moment and torque. It is now felt that a more rational approach would be to base the analysis on the buckling behaviour of the walls of the cell under combined compression and shear and choose the dimensions such that the cell will just resist buckling. The second criterion for design is taken as a limit on the twist as adapted in the case of pure torsion. Two types of sections, rectangular and circular, are discussed in this note.

NOTATION

M	bending moment at given section
T	applied torque
A	sectional area of cell
a	width of rectangular section (larger side)
b	depth of rectangular section
k	ratio a/b
p	perimeter of cell
σ	maximum compressive stress due to bending
σ_{cr}	compressive buckling stress of cell wall
τ	shear stress due to torsion
τ_{cr}	buckling shear stress
α	ratio σ/σ_{cr}
t	wall thickness of cell
R	radius of circular cell
K_1, K_2	constants in buckling stress formulae for flat panels
K_3, K_4	constants in buckling stress formulae for curved panels
E, G	elastic constants

DESIGN CRITERIA

A flat or curved panel subjected to combined compression and shear may be considered to follow a parabolic relation in its buckling behaviour[2],

$$\sigma/\sigma_{cr}=1-(\tau/\tau_{cr})^2. \quad . \quad . \quad (1)$$

From the elementary theory of torsion of thin-walled cells, the twist per unit length of a cell subjected to torque T can be represented by

$$\theta=\frac{Tp}{4A^2Gt}. \quad . \quad . \quad . \quad (2)$$

The optimum section will be such that equations (1) and (2) are satisfied, θ being the limiting twist specified by design requirements. These two criteria will be sufficient to fully determine the section. But, if there are restrictions on slope change and deflections due to bending, the dimensions of the optimum section will have to be checked against the requirements. Only the limit on twist is considered in this note.

RECTANGULAR SECTION

The maximum bending stress in a cell of rectangular section of width a and depth b subjected to a bending moment M can be seen to be

$$\sigma=\frac{3M}{bt\,(b+3a)}$$

assuming all the four walls to resist the bending moment. Substituting k for a/b which is known or determined from other requirements

$$\sigma=\frac{3M}{a^2t}\,\frac{k^2}{1+3k}.$$

The shear stress τ in the walls of the cell induced by torque T is

$$\tau=\frac{Tk}{2a^2t}.$$

The compression and shear buckling stresses σ_{cr} and τ_{cr} of the most critical wall of the box are obtained by the expressions $K_1E\,(t/a)^2$ and $K_2E\,(t/a)^2$ respectively[3] where

$$K_1=4\pi^2/[12\,(1-\mu^2)]$$

and

$$K_2=5{\cdot}35\pi^2/[12\,(1-\mu^2)].$$

assuming simply-supported condition on all four edges and μ being the Poisson's ratio of the material. Substituting for σ, σ_{cr}, τ and τ_{cr} in equation (1)

$$\frac{\dfrac{3M}{a^2t}\,\dfrac{k^2}{1+3k}}{K_1E\,(t/a)^2}=1-\left[\frac{Tk/(2a^2t)}{K_2E\,(t/a)^2}\right]^2$$

Solving the above equation for t and putting $M_1=\dfrac{Mk^2}{1+3k}$ and $T_1=Tk$.

$$t=1/E^{\frac{1}{2}}\,[1{\cdot}5M_1/k_1+\{(1{\cdot}5M_1/k_1)^2+(T_1/2K_1)^2\}^{\frac{1}{2}}]^{\frac{1}{2}}.$$

It may be observed that in this case the optimum wall thickness is independent of the absolute width or depth but dependent only on the ratio of the two.

Figure 1 gives a family of curves connecting t with t_1 and M_1 for aluminium alloy, for the ranges $0<T_1<90{,}000$ and $100<M_1<20{,}000$. It may also be noted from the formula as well as the curves in Fig. 1 that the thickness is influenced by torque appreciably only when T_1 exceeds about twice the value of M_1. Again the torque becomes the predominant factor when T_1 exceeds about 20 times that of M_1. For proportionately higher torques, the problem can be treated as one of pure torsion without introducing any serious error.

The longer side a of the section can now be obtained by substituting the known value of t in equation (2) and remembering that p the perimeter and A the sectional area are equal to $2a\,(k+1)/k$ and a^2/k respectively.

CIRCULAR SECTION

The four stresses σ, σ_{cr}, τ and τ_{cr} for a circular section of radius R and wall thickness t subjected to a bending moment M and torque T are given by

$$\sigma=M/(\pi R^2t)$$
$$\tau=T/(2\pi R^2t)$$
$$\sigma_{cr}=K_3Et/R$$
$$\tau_{cr}=K_4E\left(\frac{t}{R}\right)^{\frac{3}{2}}$$

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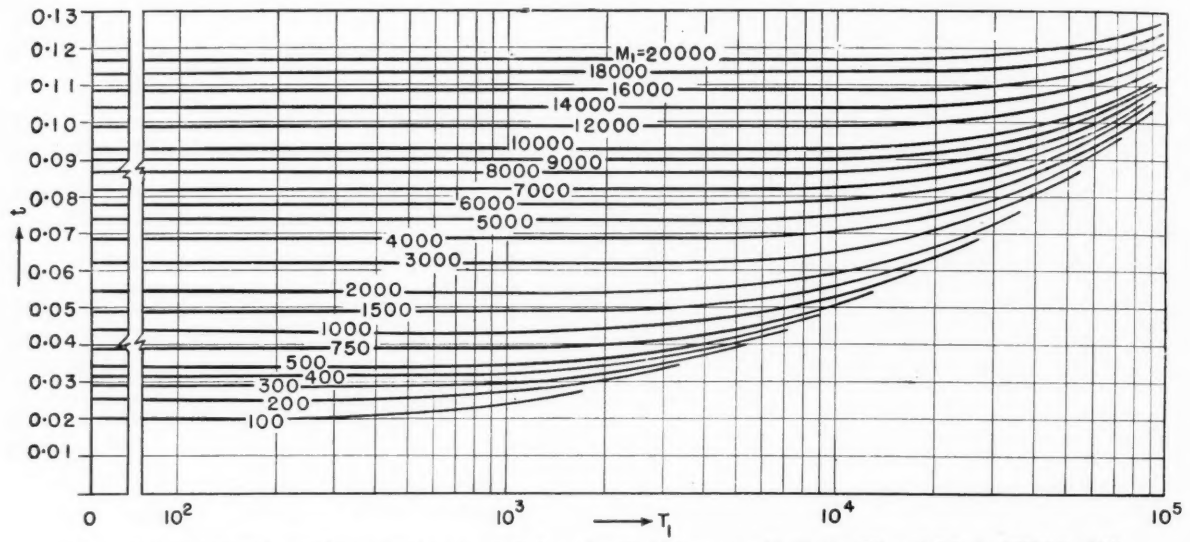

FIGURE 1. Rectangular section: showing the variation of wall thickness t with T_1 $(=Tk)$ and M_1 $[=Mk^2/(1+3k)]$.

From Ref. 3

$$K_4 = 1/[3\sqrt{2}\,(1-\mu^2)^{\frac{1}{4}}] = 0{\cdot}253$$

assuming a value of 0·3 for μ. Although according to Ref. 2 K_3 ranges from as high as 0·6 to as low as 0·16 under various conditions, a value of 0·3 more generally used for design purposes is adapted in this discussion.

A direct substitution of these quantities in equation (1) results in a 14th degree equation in t, which is inconvenient to solve. Instead a graphical method has been followed:

Putting $\alpha = \sigma/\sigma_{cr}$

we have $$\alpha = 1/(\pi K_3 E) \,.\, M/(R^2 t). \quad . \quad . \quad (3)$$

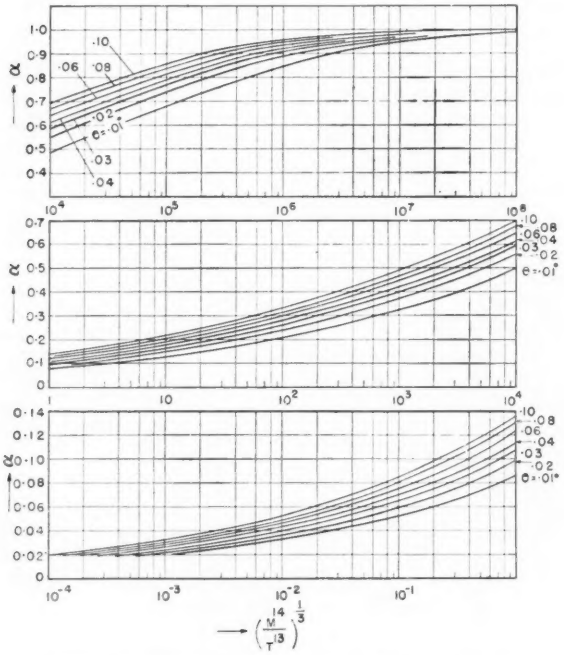

FIGURE 2. Circular section: showing the variation of $\alpha\,(=\sigma/\sigma_{cr})$ with $(M^{14}/T^{13})^{1/3}$ and θ.

From equation (1)

$$1-\alpha = 1/(4\pi^2 K_4{}^2 E^2) \,.\, T^2/(Rt^5). \quad . \quad (4)$$

From equation (2)

$$\theta = T/(2\pi G R^3 t). \quad . \quad . \quad . \quad (5)$$

Eliminating R and t from (3), (4) and (5)

$$\alpha^3\,[\alpha/(1-\alpha)]^{5/3} = 13{\cdot}77 G\theta E^{-4/3} K_3{}^{10/3} \,.\, K_4{}^{-14/3}\,(M^{14}/T^{13})^{1/3} \quad . \quad . \quad . \quad (6)$$

determining t and R in terms of α

$$t = [\alpha/(1-\alpha) \,.\, T^2/M \,.\, K_3/(4\pi K_4{}^2 E)]^{\frac{1}{4}} \quad . \quad (7)$$

$$R = \alpha^3/(1-\alpha) \,.\, (T/M)^3 \,.\, K_3{}^3 E/(8 G K_4{}^2 \theta). \quad (8)$$

Since α has to lie between 0 and 1, a plot of α ranging from 0·01 to 0·99 against corresponding values of $(M^{14}/T^{13})^{\frac{1}{3}}$ obtained from equation (6), for aluminium alloy is shown in Fig. 2. For known values of T and M, α can be read from the figure and substituted in (7) and (8) to compute the optimum values of t and R. Because of the graphical approach and a wide range of the bending moment-torque term, some error is possible and due margin will have to be allowed while choosing the thickness and radius of the optimum section.

ACKNOWLEDGMENT

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Temperature Control of Blow-Down, Supersonic Tunnels

by

T. A. THOMSON

(William and Agnes Bennett Supersonic Laboratory, Department of Aeronautics, University of Sydney)

THE BLOW-DOWN type of intermittent, supersonic tunnel is attractive because of its simplicity and because relatively high Reynolds numbers can be obtained for a given size of test section. An adverse characteristic, however, is the fall of stagnation temperature during runs, which can affect experiments in several ways. The Reynolds number varies and the absolute velocity is not constant, even if the Mach number and pressure are; heat-transfer cannot be studied under controlled conditions and the experimental errors arising from the effect of heat-transfer on the boundary layer vary in time. These effects can become significant in quantitative experiments if the tunnel is large and the variation of temperature very rapid; the expense required to eliminate them might then be justified.

The Reynolds number alone can be maintained constant by controlling the stagnation pressure to compensate for the variation of temperature. The temperature itself can be kept uniform by controlled addition of heat to the air on its way to the tunnel. The following is a review of work that has been done on methods for achieving these aims and, in particular, of the knowledge that has been gained from experiment and operating experience.

1. PRESSURE COMPENSATION

In terms of stagnation pressure, P_s, stagnation temperature, T_s, and the Mach number, M, in the test section of the tunnel, the Reynolds number per unit in the test section is

$$R_N/d\alpha P_s T_s^{-2}(T_s+120\lambda)M\lambda^{-1/(\gamma-1)} \quad . \quad (1)$$

where

$$\lambda=1+\frac{\gamma-1}{2}M^2$$

and Sutherland's Formula is used for the relation between the viscosity and the temperature (measured in deg. K.).

The Reynolds number can therefore be kept constant if the variation of temperature is compensated by control of the pressure according to equation (1). Note, however, that any change of the Mach number in the test section must be accompanied by a change of the control characteristics. Automatic control to these conditions is not excessively complex and satisfactory manual control has been achieved for a 1 in. × 3 in. tunnel[1] by continuous adjustment of the control valve to pre-calculated settings.

Advantages of the method are that no power is required for its operation, either during or before test-runs: that it does not affect the rate of utilisation of the tunnel, since no time of preparation is required, and that alterations to existing plant are not required for its installation.

Disadvantages are that, although the Reynolds number is maintained constant, forces, pressures and the stagnation temperature in the tunnel vary. Measurement of these continuously varying quantities is not regarded by Dhawan[1] as a serious difficulty, but in any case, the variation of temperature hampers the study of heat transfer phenomena.

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If no other means of controlling the Reynolds number are available, the method is an attractive "emergency measure" for any particular experiments for which constancy of Reynolds number is essential, but the other unsteady effects can be tolerated. Its employment in this way may not justify anything more complex than simple manual control.

2. ADDITION OF HEAT

However rapidly the air is discharged from the reservoirs, the fall of stagnation temperature, due to adiabatic expansion and Joule-Thomson effect, is moderated considerably by heat transfer from the walls of the vessels and pipes and, through them, from the atmosphere[1,2,3]. For instance, the fall of stagnation temperature in the 6 in. × 3 in. tunnel at the University of Sydney is only half as large as it would be if such heat transfer were absent*, and this fall could be reduced further by deliberate design of the ducts. Although conditions vary widely for different tunnels, estimates neglecting such heat transfer[4] are always likely to be considerably in error.

Electric elements may be considered as a source for the heat that must be supplied to compensate for the remaining temperature fall. They have the advantages that the high temperature differences favour an installation of conveniently small dimensions and that no time for preparation is required before runs. Disadvantages are the slow response of the element temperature to current changes, so that special precautions need to be taken to ensure adequate control of temperature fluctuations and the creation of thermal turbulence.

The accuracy required for the control of temperature depends on the permissible variation of Reynolds number and on the accuracy of pressure control. By equation (1), the percentage errors ε_R, ε_P and ε_T in Reynolds number, stagnation pressure and stagnation temperature, respectively, are related by

$$\varepsilon_T=(\varepsilon_P-\varepsilon_R)/\beta, \quad . \quad . \quad . \quad (2)$$

where

$$\beta=\left[T_s+240\left(1+\frac{\gamma-1}{2}M^2\right)\right]\Big/\left[T_s+120\left(1+\frac{\gamma-1}{2}M^2\right)\right]$$

The relation between ε_P and ε_T is shown in Fig. 1(*a*) for $\varepsilon_R=\pm 1$ per cent. and values of β which may be taken from Fig. 1(*b*).

For most accurate control of the air temperature to a uniform value, heat transfer from a source at the same temperature seems desirable. Unless the coefficient of heat transfer can be made very high, however, the area of the transferring surface needs to be very large, and it appears likely that the heat would be supplied, not so much by the external source, but rather by the surface material itself acting as a source of stored heat.

*The power required for restoring the air to its initial temperature was found to reach only 150 h.p., instead of 300 h.p., when 460 lb. of air had been discharged at the rate of 10 lb. per sec.

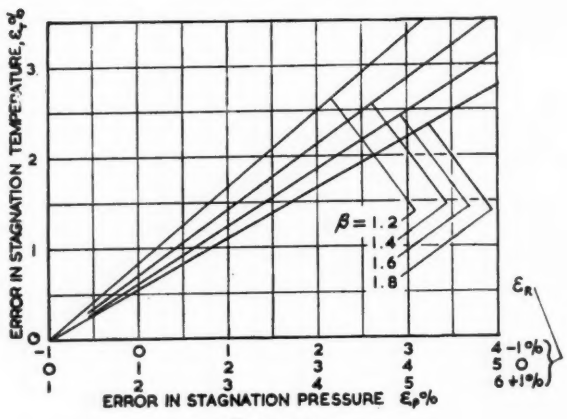

FIGURE 1*a*.

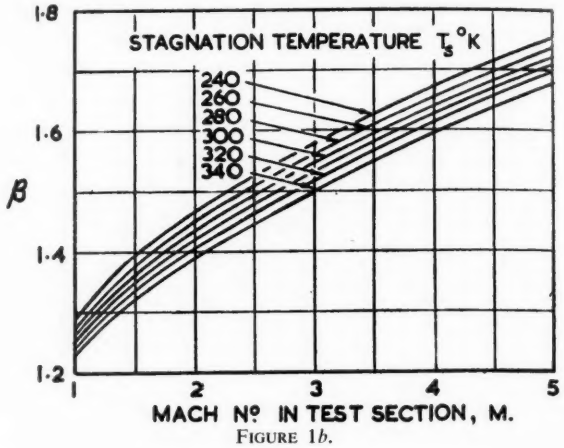

FIGURE 1*b*.

3. TEMPERATURE RESTORATION FROM STORED HEAT

The method of obtaining uniformity of temperature by passing the air through a source of stored heat, such as porous material, is shown to be possible in a theoretical treatment of heat regenerators in the unsteady state[5].

In the simplest form of the theory, the following conditions were assumed to apply:—

(*i*) The confining walls of the porous material are cylindrical and heat-insulated.

(*ii*) The properties (other than temperature) of the material are uniform throughout.

(*iii*) The pressure, density and average velocity of the air are steady and uniform throughout the material.

(*iv*) The temperatures of the air and of the material are uniform over any cross section, but upstream of the section of material, the temperature of the air varies with time at any fixed station.

(*v*) The conductive transfer of heat both in the material and in the air is negligible in comparison with the heat transfer between the air and porous material.

(*vi*) The temperatures of the air and of the material are equal at any given station and time.

If the material has a uniform initial temperature, the theory then shows that there is a *time-lag*, after the beginning of the flow, during which the air leaving the material has the same temperature. The air temperature varies at the outlet, as it did initially at the inlet, only after a certain mass of air has passed through the system. This mass is

$$m_1 = M/(s/c + \rho/h) \quad . \quad . \quad . \quad (3)$$

where M is the mass of porous material, s its specific heat and h its density; c is the specific heat at constant pressure of the air and ρ its density. As the rate of mass flow, $\dot{m}$, is constant, the time lag is

$$t_1 = m_1/\dot{m} = M/\dot{m}(s/c + \rho/h). \quad . \quad . \quad (4)$$

During this time, then, the air temperature at the outlet, $T_2(t)$, equals the uniform initial temperature, *i.e.*

$$T_2(t) = T_0 \quad . \quad . \quad . \quad (5)$$

and after the time-lag,

$$T_2(t) = T_1(t - t_1) \quad . \quad . \quad . \quad . \quad (6)$$

where $T_1(t)$ is the temperature of the inlet air.

Results of preliminary experiments[2] and of tests on a full-scale temperature-recovery unit of this type[3], with glass-wool as the porous material, confirm the effectiveness of the method*. In the tests[3], uniformity of the outlet temperature within $\pm 0{\cdot}5$ per cent. was obtained for the specified mass of air, independently of the rate of mass-flow. (Minor fluctuations could be ascribed to imperfections of pressure control.)

Secondary effects: The prediction of equation (6), however, was not confirmed by the experiments of Ref. 3 and other small-scale tests at Sydney University. The inlet temperature, T_1, fell sharply at the beginning of the test, but the decrease of the outlet temperature, T_2, was very gradual, and no similarity between the two temperature distributions was apparent at any time.

The effect of a finite coefficient of heat transfer between the air and the porous material (in contrast to equation (6)) was studied by Judd[6] and, more completely, by Pillow[5]. It corresponds qualitatively to certain features noted in the tests[3], but did not appear to suffice quantitatively to explain the experimental results. A number of other secondary effects were estimated[3] and similarly discounted and the most likely reason for the discrepancy† was thought to be a non-uniformity of the packing density of the porous material.

Small leakages of air past the porous material were found to impair the performance of the unit seriously[3], and the avoidance of leakage needs to be a major consideration in the design of the packing arrangements for the material.

Accurate control of the pressure of the air in the material is important, not only because of the effect on the Reynolds number of the tunnel if the material is in the settling chamber, but also because small variations of pressure affect the temperature of the material and of the outlet air.

3.1. *Materials*

It is obviously desirable that the material be relatively finely divided. Among other materials, glass wools and fine gravels satisfy this requirement, and Table I gives

*The time-lag, t_1, given by equation (4), was difficult to determine theoretically with accuracy, because the specific heat of the material was not known with certainty. In all tests, however, observations were maintained over periods long enough to include all possible values of t_1.

†This is not detrimental in practical applications.

TABLE I

Material	*Size*	*Density* h *lb./ft.*^{3}	*Nominal Spec. Ht.* *s*B.Th.U./lb.F°	*Time-lag,* t_1 *secs.*		
				Theoretical t_1'	*Observed* t_1''	*Ratio* t_1''/t_1'
Glass wool	0·0001 in diam.	16	0·16	10	12·5	1·25
Round gravel	0·1 in. diam.	90	0·195	67	55	0·82
Crushed basalt	mesh > 1/8 in. < 3/16 in.	79	0·195	59	44	0·75

the results of some small-scale tests to compare the performance of these materials on an equal volume basis*. While these results confirm that the performance of glass wool approaches the ideal more closely, the three materials do not differ as much in this respect as the difference in the fineness of their structure might suggest. For practical purposes, moreover, the actual magnitude of the time-lag is more important than close approach to ideal performance, and the heavier materials are therefore preferable.

It is also desirable that the material should offer relatively little resistance to air flow, but this should not be considered independently of the time-lag. For example, from Fig. 2, in the turbulent region, the 0·1 in. round gravel has approximately the same coefficient as the glass wool at 12·5 lb./ft.^{3} density, but the volume of gravel required to restore a given mass of air to uniform temperature is only about a fourth. If the gravel is employed, advantage can therefore be taken of either a lower overall pressure-loss or a container of smaller diameter.

In the choice of the porous material, consideration must also be given to the design of the installation and to possible deterioration during continued use. The use of a compressible material, *e.g.* glass wool, demands special packing arrangements to minimise variations of density due to gravity or to air forces[3]. With brittle or soft materials, deterioration due to movement under air forces and abrasion due to air shear must be guarded against.

For instance, the glass wool used at Sydney[3] was found to break up after prolonged use so that the felt screens retaining it became choked with fine glass particles, the total pressure loss became excessive and the sealing could not be maintained. With gravels, precautions must be taken to eliminate dust; preliminary tests at Sydney indicated that this can be achieved satisfactorily by washing*.

The initial cost is a factor which has discouraged the author from testing special glass wools or non-ferrous metals. With iron or steel, special precautions may be necessary to prevent damage due to corrosion.

3.2. *Location of the Temperature-Recovery Unit*

(*a*) *In Settling-chamber*: In many instances the porous material is most simply packed in the upstream end of the settling-chamber. In this way, advantage can be taken of the high coefficient of pressure loss through the material to improve the uniformity of flow into the contraction.

*Each material was packed, in turn, between screens 7⅛ inches apart in a piece of 6·1 inches diam. Air colder by 9°C than the initial temperature of the material was discharged into the pipe at a uniform rate and the time needed for the temperature at the outlet to decrease by 1°C was observed.

*The gravels were washed and air was blown through them. Some dust was observed during the first tests of the crushed basalt. Subsequent dust counts, however, indicated that this contamination was only temporary. In fact, no dust could be detected in the air either entering or leaving the material, although repeated tests were made. The count for the surrounding atmosphere, by contrast, was about 400 particles per cm^3.

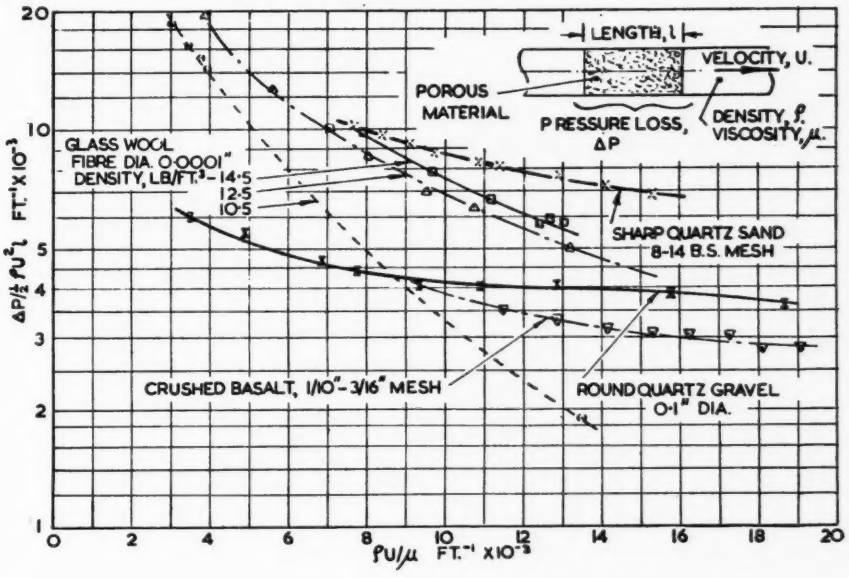

FIGURE 2. Pressure-loss of porous materials.

A disadvantage is that the temperature rises with the pressure in the settling-chamber at the beginning of a run and some heat is retained by the material instead of being swept away with the air. The process leads to non-uniform heating of the porous material and may thus cause significant variations of air temperature during the run. Tests simulating conditions in a settling-chamber* confirmed that the effect is most serious if the stagnation pressure is high and the rate of mass flow small. The character of the porous material and the size of the settling-chamber are also expected to be of importance. The tests suggested, however, that the effect is small enough to be tolerated unless very accurate control of the temperature is essential.

(*b*) *In Separate Vessel*: If the material is contained in a separate vessel upstream of the settling-chamber, several advantages may be gained. The pressure in the vessel may be raised to its operating level and thermal equilibrium attained before runs, so that the effect of initial heating is avoided. Moreover, the aerodynamic loading on the material may be reduced by operating at a suitably high pressure.

Disadvantages are the cost of the special pressure vessel and of the additional valve and the increased complexity of operation. The adoption of pressure control by reduction in two stages has the advantage, however, that the first automatic stage needs to operate only to a fixed lower level of pressure, independently of the stagnation pressure in the tunnel.

The Joule-Thomson effect in the second valve is constant and not large and, if necessary, it may be compensated for by pre-heating the porous material.

3.3. *Preparation of Porous Material before Runs*

The time required to obtain uniformity of temperature of the material merely by heat conduction and convection is excessive and provision must be made for a re-heating system. The design of this system has an important effect on the practical rate of utilisation of the tunnel. The duration of a run often does not need to be extended to the limit determined by the storage capacity, which can then be exploited for a number of runs at convenient intervals, independently of the capacity of the compressor. Heat convection during the intervals, however, changes the temperature distribution in the porous material; the number of runs available at constant stagnation temperature is thus reduced below that available at constant stagnation pressure and the rate of repetition of runs depends on the performance of the re-heating system.

*An orifice plate was fitted to the downstream end of the material testing pipe, which contained 3/16 in. gravel initially at uniform temperature. When cold air was discharged into the pipe at the rate of 0·4 lb./sec., the pressure rose to 30 p.s.i.a. and the outlet temperature of the air rose quickly by 1°C, but then settled to its initial value in about 5 seconds. When the area of the orifice was doubled, however, and the test repeated at the same pressure, no rise of temperature was observed.

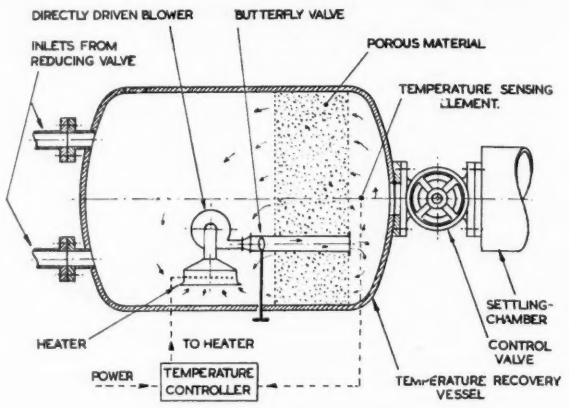

FIGURE 3. Re-heating system.

When the porous material is in the settling-chamber, re-heating may be achieved by drawing the atmospheric air into the compressor by way of the material. This implies, however, that the air supply must be recharged even after short runs and, moreover, the danger of condensation of moisture on the initially cold material constitutes a serious draw-back.

The re-heating method proposed for the tunnel at Sydney, where the porous material is in a special vessel, consists in recirculating a small quantity of air through the material, a blower and a heater. The re-heating process is to take place at the operating pressure, so that initial heating (*see* Section 3.2(*a*)) is avoided; the blower then needs to provide only a small volume-flow and pressure difference. To avoid a high pressure loading on the re-heating system, it is accommodated entirely inside the pressure vessel (Fig. 3).

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Graduates' and Students' Section

This page in the JOURNAL *is the first to be allotted to the Graduates' and Students' Section. Each month members of the committee will write on matters of interest and importance to graduates and students, as well as previewing lectures and visits.*

What does the committee of the Graduates' and Students' Section do?

This is a good place for a general survey of its work, composition and aims.

Any discussion of the committee's work should begin with a mention of its official terms of reference. These are vague and by no means detailed; they state that the committee's duties are:

1. To manage the affairs of the Graduates' and Students' Section in accordance with the objects of the Section.
2. To make recommendations to Council and to report to Council on matters affecting the graduates and students of the Society.

The committee takes full responsibility for the arrangement of all Section activities. In all those which focus on 4 Hamilton Place it is greatly assisted by the staff of the Society.

The committee normally consists of twelve members, although others can be co-opted if necessary. Nine are elected by graduates and students, two are appointed by Council and one—at present the Secretary—represents the staff of the Society. The chairman is the graduate member of Council.

The committee meets about once a month. Its standard duty is the arranging of lectures and visits.

Each year lecture programmes extend from October to May, during which, on the average, there are nine lectures and two film shows. Lectures are chosen to cover a wide range of subjects, both aeronautical and general. Lectures by graduates and students are encouraged, but not to the exclusion of one by recognised experts. Last autumn's programme was typical; lectures on structural fatigue and helicopters were given by authorities in these fields, and lectures on supersonic fighters and aeroelasticity by graduates. A film show covered rocket research. Average attendance was 87.

On the whole, lectures on general subjects seem to be more popular than those which are specialised. Suggestions for future lectures will be welcomed.

In the main, visits are made to aircraft companies and government establishments, although these are by no means the only places visited. For example, last year the Guinness Brewery was visited in response to a plea made at every Annual General Meeting. A variation on the theme this year will be a visit to a wine cellar.

Recent visits were to Hawker Aircraft, the wind tunnels at the N.A.E., Bedford, and the B.O.A.C. Stratocruiser flight simulator at London Airport.

A difficulty is that most visits must be arranged for Saturdays and evenings. Companies, however, are taking a more liberal view of visits to government establishments; those to the R.A.E. at Farnborough and the N.A.E. at Bedford were made on weekdays and many members of the Section attended, thanks to the benevolence of their companies. It is hoped that the benefit of these visits will be more widely recognised in future.

Thanks to the Secretary of the Society the Section has received its first annual grant of £25 this year. How this money is spent is the responsibility of the committee alone; in practice, it goes mainly to cover the inevitable loss on the annual dance which is held in October. This dance is becoming very popular—members receive free food and drink, and dance to a first-class band—but it can only be run at a loss. The committee is hoping that other social activities can be arranged—a summer party is a possibility this year.

The activities described take no account of the committee's interest in all matters affecting the welfare of students and graduates. An example is the recognition of the diploma of the College of Aeronautics as an exemption from Associate Fellowship examinations: this was suggested by the committee.

Publication by the Society of an unbiased guide to careers in the Aircraft Industry, describing qualifications, work done, financial prospects, etc., is another idea suggested by the committee. Such a guide would be most helpful to the Society in its drive for increased membership.

The committee is always keen to hear from members of the Section who know of any matters affecting graduates and students which they would like the committee to consider and bring to the notice of Council.

Comments on Section activities and suggestions for future lectures and visits will also be welcomed. Please send letters to the chairman, P. A. Hearne, Tiger House, Beaconsfield Road, Farnham Royal, Bucks.—J.R.C.

VISITS

In November, a large party visited London Airport, and were shown the Control Tower in some detail, and the British European Airways Engineering Base, including Viscount and Elizabethan aircraft in operational trim.

In December, a small party visited the B.O.A.C. Stratocruiser simulator. This was a short visit of about an hour, which was very interesting, particularly for those members of the party who "flew" the simulator with its almost uncanny realism.

For January, an evening visit has been arranged to a wine cellar in central London. This is to follow up the precedent of last year's visit to a brewery. The February visit will be to the de Havilland Engine Company's works at Leavesden.

Further ahead, we plan to visit a specialist car firm, a large aircraft factory near London, an operational military aerodrome and at least one government research establishment this summer.—N.K.B.

LECTURE

The Section's next lecture, "An Introduction to Kinetic Heating," will be given by J. B. Edwards (Graduate), of Handley Page, in the Library, 4 Hamilton Place, W.1, at 7.30 p.m. on Tuesday 31st January.

THE LIBRARY

Reviews

AN INTRODUCTION TO ELECTRONIC ANALOGUE COMPUTERS. *C. A. A. Wass. Pergamon Press Ltd., London, 1955. 237 pp. Illustrated. 40s.*

This is the first British textbook devoted solely to electronic analogue computors. It comes from an author in the Royal Aircraft Establishment, the home of many computors including TRIDAC, one of the largest such machines in the World. Much of the development of these computors since the early days of the War was carried out in this Establishment, the author being at all times closely associated with the work. To many scientists and engineers the analogue computor has become a common-place and accepted research tool, and thus the publication of this book is timely and should fill an important gap in the literature.

In the introduction the essential difference between analogue and digital computors is considered and the fields of application of both are given. An important point, the clarification of the terms Differential Analyser, Simulator and Analogue Computor are dealt with at an early stage. Not all readers, however, will agree that a simulator should be restricted to have a one-to-one time scale with the system it is intended to simulate. To the engineer familiar with rotating electrical machinery, the use of d.c. machines and a.c. machines as the terminology for two types of analogue computors, will raise a smile.

The book deals exclusively with electronic systems but little if any knowledge of electronics is required for an understanding of the text. Some electro-mechanical devices are described however in connection with non-linear function generators which form one of the units of many analogue computors.

Initially, the various elements that are required for basic computation are enumerated; then, via a section on negative feedback, the electronic means of achieving these requirements are described. By Chapter 3 the reader is dealing with simple but complete simulator systems. D.c. amplifiers which form the kernel of all analogue units are discussed at length with circuit details and considerations of drift and drift compensation. Limitations of practical systems, non-linear computing elements and auxiliary apparatus are all chapter subjects. The closing chapters deal with the use of simulators, scale factors, time scales, the various classes of machines and finally a description of existing machines including TRIDAC. At the end is given an adequate bibliography, subject and author indexes.

The book is easy to read and will be of value to a large group who are interested in the subject in addition to potential and existing designers and computor users.—J. C. WEST.

CHEMICAL REACTIONS IN FLOW SYSTEMS. *S. S. Penner. Published for and on behalf of AGARD by Butterworths Scientific Publications. London, 1955. 86 pp. Diagrams. 21s.*

This book, published on behalf of the Advisory Group on Aeronautical Research and Development of the North Atlantic Treaty Organisation, and written by one of the most active workers in this group, is intended to summarise the principles of chemical kinetics for non-chemists, and to show how problems combining flow and chemical reactions should be formulated.

This field of study may be divided up as follows: (*i*) Chemical reaction rate: attention is concentrated on a differential volume of the gas and the strengths of the sources and sinks of matter and energy are related to the temperature and composition of the gas. (*ii*) Physical transport: attention is concentrated on the boundaries of the differential volume and the relations between the heat and matter fluxes across these boundaries and the gradients of temperature and concentration. (*iii*) Inter-relation of (*i*) and (*ii*) in systems uniform in ultimate composition: laminar flame propagation and re-heat combustion belong to this part of the field. (*iv*) Inter-relation of (*i*) and (*ii*) in systems of non-uniform ultimate composition: droplet combustion and turbulent diffusion flames belong to this part of the field. Dr. Penner's four chapters roughly correspond to this sub-division.

Chapter I contains the equations relating the rate of a given reaction to the concentration of reactants and to the temperature, and relating the overall rate of reaction to the rates of component reactions for various complex reaction schemes. Reaction rate is expressed as rate of change of concentration with time as is common in chemical kinetics, although in reacting flow systems the concentration is often constant. Dr. Penner does not deal with this point. Otherwise the treatment is erudite and concise, although it makes great demands on the reader.

Chapter II presents the equations of continuity, motion and energy for reacting systems in a general form. These are followed by relations, derived from the kinetic theory of gases, between the transport properties and molecular properties, the formulation being generally that of Hirschfelder and his collaborators although much condensed. For understanding the reader must go to the standard texts, but as a selection of relevant formulae the chapter is valuable.

Dr. Penner deals with aspects (*iii*) and (*iv*), mentioned above, by way of examples. Reactions in gases of homogeneous ultimate composition are represented, in Chapter III, by a treatment of chemical reaction in a gas flowing through a convergent-divergent nozzle. Although this can certainly be called a flow system, it lacks the typical features of such systems, *viz.* transport due to temperature, concentration, and velocity gradients. The treatment is based on that of earlier publications by Dr. Penner and his associates.

Chapter IV, entitled "Heterogeneous Chemical Reactions," begins with a brief mention of the role of solid surfaces in gas reactions, and then proceeds to a discussion of droplet combustion. Dr. Penner does not attempt to review the present state of knowledge in this field or to show its relation to the wider class of phenomena mentioned under (*iv*), preferring to use his limited space for detailed treatment of a single aspect of the problem, namely how to account for the variations of thermal conductivity, and so on, with temperature. Most previous workers had been content to take mean values of conductivity and specific heat when calculating burning rate, flame temperature and flame position. The treatment is based on an earlier publication by Goldsmith and Penner. Dr. Penner does not discuss the phenomena, first predicted by Zeldovich, which occur when the physically-controlled transport rates exceed the capacity of the chemical

reactions. The ensuing extinction is interesting for the light it throws on problems of combustion in aero-engines at high altitudes.

AGARDOGRAPH 5. *Anthropometry and Human Engineering. A.G.A.R.D. Butterworths Scientific Publications, 1955. 123 pp. Illustrated. 21s.*

AGARDOGRAPH 6. *Collected Papers on Aviation Medicine. A.G.A.R.D. Butterworths Scientific Publications, 1955. 208 pp. Illustrated. 37s. 6d.*

Experience gained by the Allied air forces during the Second World War pointed to the need for a systematic study of the particular man-machine combination exemplified by the military aircraft and its operational aircrew. Out of this need arose the applied science of Aviation Medicine which embraces the study of human and environmental factors governing man's performance in the operational aircraft and the development of equipment to extend performance within the limits set by the military task. Current trends in aircraft performance towards greater speeds and higher altitudes and their implications for the human operator continue to give impetus to these studies.

These two Agardographs contain a series of scientific papers on aviation medicine and related topics presented at A.G.A.R.D. meetings. " Anthropometry and Human Engineering " has a misleading title as it consists of papers given at a symposium on these subjects in relationship solely to military aircraft operation. The " Collected Papers on Aviation Medicine " were read at meetings of A.G.A.R.D. Aeromedical Panel, at a joint meeting of Aeromedical and Flight Test Panels or before A.G.A.R.D. General Assemblies. The differing aims of these meetings have resulted in a miscellany of papers varying widely in approach and level of treatment. Such diversity is an asset in a work of this kind provided that the evanescent and the superficial are eliminated by careful editing. Unfortunately, neither of these volumes has an editor and for this reason all the flaws inherent in their origin are apparent. The papers lack uniformity, and the aim of the book is not clear, a detailed description of electronic techniques finds a place amongst informed reviews on more relevant topics, and the high quality of many of the papers is offset by the fact that where an editor would have selected, these papers have been collected. Several papers are in the form of lecture notes, some include figures with inadequate captions and no textual explanation, and one paper is the introduction to a film which the reader will never see. An abstract of the discussion on some of the more controversial papers would have increased their value for the non-specialist reader.

While these two books are primarily of interest to the aeromedical specialist, about one third of their contents should be of particular interest to the aeronautical engineer. Probably the most important contributions from the designer's point of view are those dealing with the physical characteristics of the aircraft cockpit, a subject well covered by informed papers on cockpit layout and sizing, cockpit instrumentation and requirements for pressure cabins. A paper on human body measurement draws attention to the limitations which non-standard cockpits may place upon aircrew selection and the ease with which aircrew may be transferred from one type of aircraft to another. In some of the more general papers problems of climatic conditions in current and future aircraft are briefly discussed. Several other papers will provide useful background information for the engineer; of particular interest, because of its implications for crash protection, is a detailed report on the effects of abrupt deceleration on human and animal subjects. In addition, papers on high intensity noise in aircraft carriers, arctic survival, and the more general papers on aviation medicine should prove of interest to the non-medical reader.—H. LUNDY (R.A.F. Institute of Aviation Medicine).

BASIC LUBRICATION PRACTICE. *Allen F. Brewer. Reinhold Publishing Corporation, U.S.A., 1955. 286 pp. Illustrated. 54s.*

The efficient lubrication of modern industrial and power plant machinery has developed into a somewhat exacting science, and in his book, *Basic Lubrication Practice*, Mr. Brewer makes a commendable attempt to summarise all the available information on this topic in a concise and readable form.

In contrast to many writers who have discussed the more theoretical side of this subject, Mr. Brewer has concentrated on practical applicational aspects and for this reason his book is to be recommended to the practical-minded engineer, rather than to the research student. Lubrication and maintenance engineers in particular should find this a handy reference volume, since it contains a wealth of useful practical information in the form of charts, illustrations and tabular data.

In the opening chapter, the important factors which influence the demands made on the lubricant are discussed, and this is followed by a description of the standard test methods which are used to evaluate the physical properties of lubricants. The tests are well described and amply illustrated and (perhaps more enlightening) the practical significance of each test is stated. It is noteworthy that the author quotes the views of the American Society For Testing Materials (A.S.T.M.) rather than his own thoughts on this subject.

The remainder of the volume is divided into sections dealing with different types of application such as bearings, gears, wire ropes, flexible couplings, cams, steam-turbines, internal combustion engines, power plant auxiliaries, electric motors, and so on. In each section, factors which influence the choice of lubricant are discussed, together with recommended methods of application.

Lubricants are often wrongly blamed for troubles which arise in modern machinery and Mr. Brewer gives some sound advice on the more common operating difficulties which arise in the various types of equipment. His tables of " Do's and Don't's " and his " trouble shooting guides " clearly indicate that modern machinery has to be lubricated intelligently if the best results are to be achieved.

Mr. Brewer is to be complimented on his presentation of a somewhat involved subject in a systematic and practical manner. For those who wish to obtain more detailed information on various aspects of the subject, he has included a useful series of references at the end of each chapter.—D. REECE (Thornton Research Centre).

BERICHT UBER DEN V. INTERNATIONALEN ASTRONAUTISCHEN KONGRESS (Proceedings of the Fifth International Astronautical Conference, Innsbruck, August 1954). *Edited by F. Hecht. Springer, Vienna, 1955. In English, French, German or Italian. 307 pp. Illustrated. £5.*

This volume, apart from the papers it contains, is a remarkable commentary on Life as it is Today. At the time the Fifth International Astronautic Congress was held, those attending it were regarded by most of the civilised world (sic) as cranks and crackpots. Their papers were probably either ignored as fantastic dreams or laughed at as childish materials that should be on the front page of the *Eagle*. In other words, Astronautics was where

Aeronautics were in 1903. Now, as a result of competitive announcements by this country, the U.S.A. and the U.S.S.R. astronautics have suddenly become respectable and this volume will probably be found in every newspaper library. In fact, one of the papers is entitled " The Respectability of Astronautics as reflected by Recent Developments in the United States." Respectability is the operative word.

The papers show that the pre-natal treatment of Astronautics is far more scientific and well-prepared than was that of Aeronautics. Brilliant men obviously believed in it and have believed in it for a long time and, with the scientific advances gained over two wars, the new science should not spend such a long time tottering on unsure feet.

Some of the papers in the volume have already appeared in *Astronautica Acta* but the collection of the whole proceedings forms an essential addition to the library of any body or anybody concerned with anticipating the development of space flight. The writer of these notes is concerned to know, what is the Society's place in all this? —F.H.S.

SERVOMECHANISMS AND REGULATING SYSTEM DESIGN. *Vol. II. H. Chestnut and R. W. Mayer. John Wiley and Sons, New York, 1955. 384 pp. Diagrams. 68s.*

Vol. I of this work was published in 1951, and dealt with the fundamentals of servo-mechanism theory. The present volume applies the principles set out there to the practical design of control systems.

The book opens with a chapter on techniques for measuring actual system parameters and performance. The relative merits of transient and frequency responses are set forth, and the usual graphical vector method of converting the first type to the second is given. Next follows a chapter on the influence of input characteristics on the design process; idealised inputs are introduced, and illustrated by a target-tracking device. The problem of noise is treated briefly, but with adequate references to the literature. The principles governing the selection of a passive network to modify system performance are described and a large selection of such networks is presented in chart form, with their transfer functions and attenuation/frequency characteristics. Amplifier design is treated at some length, with particular reference to those characteristics that are important in servo systems. The causes of drift in d.c. amplifiers are analysed, formulae are given for the amount of drift due to each cause, and suitable compensating circuits are described. The last three chapters, totalling almost half the book, are devoted to various aspects of non-linearity. The emphasis is on approximate methods enabling qualitative results to be obtained for complicated systems, rather than the development of more sophisticated mathematical techniques. For small departures from an operating point, the principle of linearisation is explained. For large departures, the " describing function " concept is developed and applied to various common types of non-linear element. The final chapter deals with the deliberate introduction of non-linearity into a system. A bibliography is given, arranged in chronological order, containing 117 references, one of which is British.

The book as a whole gives one the strange feeling that the authors are not entirely happy with mathematics. This is distinctly more noticeable in Vol. I, although the impression persists in the present volume. There are a few unusual mistakes of an elementary nature—for example, the graph of a function $y(t+1)$ against t is drawn as the graph of $y(t)$ displaced in the wrong direction. A load inertia is given in foot pounds squared. There is little new to be found, and the book may be considered an acceptable alternative to most of the numerous other books on the same subject.—S. J. GARVEY.

THE COMET RIDDLE. *Timothy Hewat and W. A. Waterton. Muller, 1955. 160 pp. 12 plates. 10s. 6d.*

We shall long remember the explosions which brought two of B.O.A.C.'s Comets crashing into the Mediterranean in the early months of 1954. To the general public they represented promise unfulfilled. Immediately after the War, American aeroplanes dominated in the air transport fields and, rather than waste time with piston-engines, some of our manufacturers set out boldly to use the turbo-jet. The early successes of the Comet were a symbol of our civil aviation recovery from the War, but when the Comet I failed, the sky looked black again. To those more intimately connected with aviation the accidents and the subsequent enquiry will be remembered on two counts: the magnificent detective work which revealed the cause of the first crash and the revelation that pumping up the fuselage once per flight could fatigue an otherwise strong structure.

The work of accident investigation is so often secret that the techniques used and successes gained are little known. The account of the recovery from the sea of the Elba Comet, of its piecing together at Farnborough and of the deductions made about the order of the structural failures is one of the great detective stories of our time. The news that fatigue in the metal of the fuselage was the cause of the failure surprised most people in aviation. Thanks to Nevil Shute the public half expected a fatigue failure on any trans-ocean flight but the technician found it difficult to imagine statically strong metal being broken by a few *hundred thousand* reversals of a load well below the critical. The suggestion that a few *thousand* reversals could break it seemed ludicrous. Another expensive stage in our education had passed.

In this account of the Comet accidents, Messrs. Hewat and Waterton tell the whole story of the Comet. The book is not primarily for the technician and the bare story is embroidered by the " background " so beloved by press-men. The story of de Havillands is here (we are even told how many shares the Prudential hold); the story of the R.A.E. (Empress Eugenie of France chose to die at Farnborough) and the story of Sir Arnold Hall whose " face in profile is like a triangle with two sides running to a point at the nose." In case readers are misled there is an excellent full-page photograph of Sir Arnold. We are told Sir Arnold's salary at R.A.E.—" about a third of the pay he would get in private industry in Britain." Really! Mr. Hewat is putting ideas into the heads of our Civil Servants.

I very much enjoyed reading the story of the Comet again. Although the authors make no attempt to put forward any ideas or criticisms that were not advanced at the Inquiry their account is most readable.—A. H. YATES.

HYDRODYNAMICS. *Garrett Birkhoff. Dover Publications, New York. 186 pp. Diagrams. $1.75.*

In previous reviews of the Dover publications, mention has been made of the great service this house performs in re-publishing classics in technical literature which have been unobtainable for years and at a competitive price. The reviewer is not sure whether this latest addition to the list is unobtainable in its original form but it does seem an almost indecently short time (1950) after to produce a cheap reprint. There can be nothing but praise for an arrangement that enables University students to obtain new copies of standard books at prices at the Penguin level.—F.H.S.

THE ELEMENTS OF THE THEORY OF REAL FUNCTIONS. *J. E. Littlewood. Third Edition. Dover Publications, New York. 71 pp. $1.35.*

This is another of Dover Publications' " re-published classics " and is an extensive revision of the second British edition. The book, which is for final-year undergraduate and first-year graduate courses, contains the substance of lectures delivered by Professor Littlewood at Cambridge University.—E.C.P.

AIRCRAFT ENGINES OF THE WORLD. *Paul H. Wilkinson. Pitman, London, 1955. 320 pp. Illustrated. 50s.*

The object of a review is, of course, to persuade someone to buy a book or dissuade him from doing so. Some books will be bought irrespective of what you say or what you do not say and the subject of this " Review " is one of that category. It has been published every year since 1944 and before that in 1941. If it were not worth buying it would not have lasted that long. A useful note in the Preface tells us that it is up-to-date, " as of 1st May 1955," so that it is of no use looking, for instance, for the Gyron. This is, however, indexed and on looking up the appropriate reference we find a short note that it is beginning flight tests and an approximation of its thrust. The tabulation and sub-division of the latest edition is as easy and quick to use as it always has been.—F.H.S.

THE AEROPLANE DIRECTORY OF BRITISH AVIATION. *1955 Edition. London Temple Press Ltd. 582 pp. 21s.*

One does not review " The Aeroplane Directory." The reviewer who looks up the entries that are of closest interest to him *might* find a mistake and comment on it. On the whole one just takes a very useful book of reference for granted and puts it on the corner of the desk where it has been a standby for " more years than one cares to remember."—F.H.S.

AIRCRAFT POWER PLANTS. *C. E. Chapel, R. D. Bent and James L. McKinley. Second Edition. McGraw-Hill, 1955. 392 pp. Illustrated. 60s.*

This is the Second Edition of a book first published in 1948 and written by the Technical Development Staff of Northrop Aeronautical Institute. With its companion volumes, *Aircraft Basic Science* and *Aircraft Maintenance and Repair,* it is intended " to encompass information on all phases of airframe and power-plant operation and maintenance."

This revised edition of *Aircraft Power Plants* has been brought up to date by the addition of new descriptive material and illustrations on aviation fuels, carburettors, direct fuel injection, superchargers, low-tension ignition systems, spark plugs, engine-analysing and testing equipment, automatic and controllable propellers, turbo-jet engines and compound engines. The number of pages is slightly more but the price has increased substantially, at least in this country.

AMERICAN AVIATION WORLD-WIDE DIRECTORY. *Volume 16, No. 2. Fall-Winter 1955-1956. Editor, Marion E. Grambow. American Aviation Publications, Washington. 1955. 794 pp. $7.50.*

There are certain books of reference to which all librarians look forward as they become due because they are stock stand-bys and enable the user to provide up-to-date and reliable information " off-the-cuff." Such a book is this Directory with its unique coverage of organisations, personnel, firms and what have you in the world of aviation. It will, for instance, save you confusing Airwork Corp. with Airwork Ltd. The American coverage is, of course, the most comprehensive—equipment, manufacturers, government, " special services " and the rest but the foreign section is remarkably informative and only the need to use this " mine of information " will prove its value, even at $7.50 each half-year.—F.H.S.

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**Items marked thus are for reference use only.*

Reports

AERODYNAMICS

Boundary Layer

Methods of determination and of fixing boundary layer transition on wind tunnel models at supersonic speeds. K. G. Winter et al. A.R.C. C.P. No. 212 (*September* 1954, *published* 1955).

An account is given of methods used in supersonic wind tunnels for observation of boundary layer phenomena, in particular of the sublimation and oil film techniques. Examples are given of the uses of these techniques. On the fixing of transition a rough guide is given for the minimum size of wire required, with an example of the use of wires. The results of a brief experiment on the profile of an artificially promoted turbulent boundary layer are also given. —(1.1.2).

Turbulent boundary layer control by ramps or wedges. A. V. Stephens and G. A. Collins. A. A.R.C. Report ACA-55 (*May*, 1955).

Part I describes preliminary experiments of a new device for the delay or elimination of turbulent separation. The device is essentially a means of redistributing the total pressure in a boundary layer by means of wedge-shaped excrescences on the surface. The experiments, which were done on the floor of the open return wind tunnel at Cambridge during the latter part of 1950, seemed to establish that the device did materially increase the total pressure close to the surface. Part II deals with the continuation of these experiments in 7 ft. × 5 ft. wind tunnel at Sydney University. The operation of boundary layer wedges for controlling turbulent separation was investigated in an adverse pressure gradient on the upper surface of a wing. A new type of wedge in the form of a flat ramp was developed. —(1.1.4).

Grenzschichtuntersuchungen in rotierenden Kanälen und bei scherenden Strömungen. G. Jungclaus. Max-Planck-Institut. Nr. 11 (1955).

Compressible Flow

*Analytical treatment of two-dimensional supersonic flow. Part II: Flow with weak shocks. J. J. Mahony. A.R.L. Report A.*94 (*April* 1955).

A scheme of approximate solution is presented for the treatment of shock waves in the steady, plane flow of a perfect gas. It is based on the neglect of entropy variations produced by the shocks and hence is applicable only when the shocks are weak. The method provides an extension of Friedrichs' results for simple waves to wave interactions. Simple typical examples are worked out. A brief discussion is given of the validity of using homentropic theory and estimates of the errors involved are obtained.—(1.2.3).

Aerodynamic heating versus speed thermodynamic: aspects of the struggle. M. Roy. O.N.E.R.A. Publication No. 77 (1955). —(1.2.3).

Proper combination of lift loadings for least drag on a supersonic wing. F. C. Grant. N.A.C.A. T.N. 3533 (*October* 1955).

Lagrange's method of undetermined multipliers is applied to the problem of properly combining lift loadings for the least drag at a given lift on supersonic wings. The interference drag between the optimum loading and any loading at the same lift coefficient is found to be constant on a given plan form. This is an integral form of a criterion established by R. T. Jones for optimum loadings. The best combination of four loadings on a delta wing with subsonic leading edges is calculated for several Mach numbers as a numerical example.—(1.2.3).

Flight investigation of the surface-pressure distribution and the flow field around a conical and two spherical nonrotating full-scale propeller spinners. J. B. Hammack et al. N.A.C.A. T.N. 3535 (*September* 1955).

The surface-pressure distribution and the flow field around a conical and two spherical non-rotating full-scale propeller spinners were determined in flight at Mach numbers of 0·70 to 0·96. The local-surface Mach numbers between the cone-sphere tangency and the maximum thickness stations were approximately 0·4 higher than those at a free-stream Mach number of 0·95.—(1.2.1).

Approximate solution for axially symmetric flow over a cone with an attached shock wave. R. A. Hord. N.A.C.A. T.N. 3485 (*October* 1955).

It is shown that the streamlines in an angular neighbourhood of the surface of an unyawed circular cone with an attached shock wave are, to a first approximation, portions of hyperbolas. This fact is used as a basis for the development of an approximate solution in which shock-wave orientation and flow field behind the shock wave are given explicitly in terms of free-stream Mach number, vertex angle of the body cone, and the ratio of specific heats of the gas. The approximate solution is compared with other approximate solutions for the cone.—(1.2.3).

Control Surfaces

Analysis of aerodynamic data on blowing over trailing edge flaps for increasing lift. J. Williams. A.R.C. C.P. No. 209 (*September* 1954, *published* 1955).

Available results on blowing over trailing edge flaps are discussed and the force measurements from wind-tunnel tests are correlated in terms of the blowing moment coefficient. Simple methods are tentatively suggested for the practical prediction of the lift increment (at constant incidence) attainable on finite wings, and the associated increase in pitching moment. Theoretical curves, relating to compressible isentropic flow through the blowing slot, are presented for the determination of the various blowing coefficients in terms of the blowing pressure ratio.—(1.3.4).

Visualization study of secondary flows in turbine rotor tip regions. H. W. Allen and M. G. Kofskey. N.A.C.A. T.N. 3519 (*September* 1955).

A low-speed visualisation study of turbine rotor tip secondary flows was made. Results include qualitative information on tip-clearance flow, cross-passage flow, and scraping flow, and on a range of rotor speeds for which a transition condition appeared with minimum flow disturbance.—(1.3.3.2).

Limited flight investigation of the effect of three vortex-generator configurations on the effectiveness of a plain flap on an unswept wing. G. J. Morris and L. J. Lina. N.A.C.A. T.N. 3536 (*September* 1955).

An exploratory flight investigation was made to determine the effect of three vortex-generator configurations on the effectiveness of the plain flap of a fighter aeroplane. Tests were made with flaps deflected 19° and 45° at several indicated air speeds in the range from stall to 140 m.p.h.—(1.3.4 × 1.10.2).

Fluid Dynamics

On the development of turbulent wakes from vortex streets. A. Rosiko. N.A.C.A. Report 1191 (1954).

Wake development behind circular cylinders at Reynolds numbers from 40 to 10,000 was investigated by hot-wire techniques in a low-speed wind tunnel.—(1.4).

Theories of turbulence. L. Agostini and J. Bass. N.A.C.A. T.M. 1377 (*October* 1955).

A discussion of the kinematics of statistical mediums, particularly those which are isotropic, is included and a mathematical study is made of the applications of Navier's equations to turbulent motion. Physical theories involving similarity are dealt with and much of the work in turbulence is reviewed. The theoretical discussions are illustrated by some correlation and spectrum curves based on measurements taken in the wind tunnel at the laboratory of the mechanics of the atmosphere at Marseille.—(1.4.2).

NOTE.—*The figures in parenthesis at the end of each Summary are for office use only.*

Intensity, scale, and spectra of turbulence in mixing region of free subsonic jet. J. C. Laurence. N.A.C.A. T.N. 3561 (*September* 1955.

Hot-wire anemometer measurements of the turbulence parameters were made in a 3·5 inch diameter free jet at exit Mach numbers between 0·2 and 0·7 and Reynolds numbers (based on jet rad.) between 37,500 and 350,000.—(1.4).

An experimental comparison of the Lagrangian and Eulerian correlation coefficients in homogeneous istotropic turbulence. W. R. Mickelsen. N.A.C.A. T.N. 3570 (*October* 1955).

The Lagrangian and Eulerian correlation coefficients were compared in a field of homogeneous, isotropic turbulence. The Lagrangian correlation coefficient was characterised by diffusion measurements, and the Eulerian coefficient was measured by hot-wire anemometry.—(1.4.2).

INTERNAL FLOW

See also THERMODYNAMICS: HEAT TRANSFER

Application of the Lightill mathematical method to the test cascade design. A. W. Wright and E. Szomanski. A.R.L./M.E. 201 (*June* 1955).

An attempt is made to expand the Lighthill method of cascade design in such a manner that the newcomer to the field, providing that he has a grounding in conformal transformations and complex variable theory, may proceed to its successful application to design, substantially without tutorial assistance. Also included are modifications and extensions to the original method which have proved to be useful in the designs completed so far.—(1.5.4.1).

PERFORMANCE ESTIMATION

Optimal trajectories in the horizontal plane. H. Behrbohm. S.A.A.B. T.N. 33 (*March* 1955).

The following two problems are treated: (1) to determine a zero-yaw optimal-time flight path in the horizontal plane in such a way that, when taking into consideration the weight change, the Mach-effect on drag, and the effect of speed on thrust, a body from given magnitude and azimuth of the velocity vector in the starting point reaches a given speed and azimuth in the end point of the path (the geometric positions of the initial and end points are not of interest in this connection). (2) to determine a zero-yaw flight path in the horizontal plane in such a way that a body (of constant weight) from a given speed and azimuth angle in the starting point in optimal time reaches a point moving along a known path in a known manner. For both of these problems the necessary conditions for the extremals are derived in the form of Euler's differential equations, and a close discussion is given.—(1.7).

Optimal trajectories in the vertical plane. H. Behrbohm. S.A.A.B. T.N. 34 (*April* 1955).

To complement more general investigations concerning brachistochrome flight paths in three dimensions, some special optimum problems of the vertical plane flight are discussed in somewhat greater detail. They are the problems of the time-optimal and of the fuel-optimal flight paths with prescribed endpoints, the problem of the highest climb and the problem of the most distant climb in a given time. The related systems of Euler equations are put into a form convenient for machine computation. Mach number dependency of the drag, Mach number and altitude dependency of the thrust and variability of the weight are taken into account.—(1.7).

Optimum flight paths of turbojet aircraft. A. Miele. N.A.C.A. T.M. 1389 (*September* 1955).

The climb of turbo-jet aircraft is analysed and discussed including the effects of tangential accelerations. Three flight performances are examined: minimum time of climb, climb with minimum fuel consumption, and steepest climb. Diagrams for quick calculation of the optimum Mach numbers and the effect of acceleration on the rate of climb in tropospheric and stratospheric flight are given.—(1.7).

WINGS AND AEROFOILS

See also AERODYNAMICS: CONTROL SURFACES

Proprietes calculées d'ailes en delta échancré ou non. L. Malavard et al. O.N.E.R.A. Note Technique No. 25 (1955). —(1.10.1.2).

Wind-tunnel investigation at low speed of effect of size and position of closed air ducts on static longitudinal and static lateral stability characteristics of unswept-midwing models having wings of aspect ratio 2, 4, *and* 6. *B. M. Jaquet and J. L. Williams. N.A.C.A. T.N.* 3481 (*September* 1955).

Results are presented of tests made at a Mach number of 0·13 in the Langley stability tunnel to determine the effects of closed wing-root air ducts on the static longitudinal and static lateral stability characteristics of models having unswept wing and tail surfaces with wings of aspect ratio 2, 4, and 6. In addition, for model configurations employing the wing of aspect ratio 2 the effects of top and bottom fuselage ducts on the static longitudinal and static lateral characteristics were determined. The effect of the wing-root ducts on the aerodynamic hysteresis in sideslip of the model employing the wing of aspect ratio 2 was also determined.—(1.10.2.2).

Measurements of the effects of finite span on the pressure distribution over double-wedge wings at Mach numbers near shock attachment. W. G. Vincenti. N.A.C.A. T.N. 3522 (*September* 1955).

Results are presented of measurements at low supersonic speeds of the pressure distribution on two wings having a common double-wedge section and aspect ratios 2 and 4. Comparable results for aspect ratio infinity have been published in N.A.C.A. T.N. 3225. The results cover the Mach number range from 1·166 to 1·377, which brackets the value (1·221) for bow-wave attachment at zero angle of attack. The data are discussed and compared with the previous two-dimensional findings.—(1.10.2.2).

Low-speed static lateral and rolling stability characteristics of a series of configurations composed of intersecting triangular plan-form surfaces. D. F. Thomas, Jr. N.A.C.A. T.N. 3532 (*October* 1955).

The static lateral and rolling stability derivatives of a series of cruciform, inverted T-, V-, and Y-configurations composed of low-aspect-ratio triangular surfaces have been obtained at low speed in the 6-foot-diameter rolling-flow test section of the Langley stability tunnel. These derivatives are presented as functions of the geometry of the models, and for two configurations (a planar wing and an inverted T), as functions of angle of attack. Where possible, comparisons have been made to indicate the extent of agreement between experiment and existing theory.—(1.10.2.2).

TESTING AND INSTRUMENTS

Some notes on the calculation of pressure pick-up sensitivity and the conditions for maximum sensitivity and The development of a miniature pressure pick-up. J. K. Friswell, A.R.C. C.P. No. 199 (*March* 1954).

A theoretical analysis is made of the sensitivity of a pressure pick-up of the strain gauge cantilever type and of the conditions for maximum sensitivity. Two different configurations are treated and the effect of tension in the diaphragm is also considered. An account is given of experiments to verify the analysis and to observe the behaviour outside the range of validity of the theory.—(1.12.6.1).

Experiments on a slotted wall working section in a wind tunnel. F. Vandrey and K. Wieghardt. A.R.C. C.P. No. 206 (*March* 1952, *published* 1955).

This investigation was undertaken to develop a test section for a planned water tunnel with the correction properties of a free jet, but with a considerably greater length than a conventional open-working section. The experiments were made in air ($V = 96$ f.p.s.) with a jet of 5 in. diameter and 30 in. length, enclosed in a cage of 16 longitudinal rods with an opening ratio of 18 per cent. of the total boundary. The cage was surrounded by a rigid cylinder of 12½ in. diameter representing the outer boundary of the water tunnel. —(1.12.1.1).

Further experiments with a slotted-wall test section. F. Vandrey. A.R.C. C.P. 207 (*March* 1953, *published* 1955).

As shown by previous experiments, a slotted-wall test section is especially suitable for a water tunnel intended

for the testing of long models. The present report deals with the transition from this type of test section to the diffuser.—(1.12).

Non-existence of steady acoustic lag in airborne pressure measuring systems. B. G. Newman. N.A.E. Laboratory Report L.R.-100A. (July 1955).

This is a corrigendum to Report L.R.100. It is established experimentally that the, so-called, acoustic lag in the tubing of pressure measuring systems is non-existent for the simple case when the time rate of change of pressure is approximately constant. This conclusion is supported by a theoretical analysis.—(1.12).

Automatic pressure measuring systems used with high-speed wind tunnels. C. L. Frederick et al. AGARDograph 10 (*June* 1955).

A survey of the principal devices and typical systems developed for automatic pressure measurement in high-speed wind tunnels in the United States.—(1.12.6.1).

Dynamic measurements in wind tunnels. L. Arnold. AGARDograph 11 (*August* 1955).

The state of the art of measuring unsteady aerodynamic forces and of testing dynamically similar models in wind tunnels, both from the standpoint of dynamic stability and flutter. A description of accepted procedures developed in N.A.T.O. countries.—1.12).

Turbulence measurements with the hot-wire anemometer. R. D. Cooper and M. P. Tulin. AGARDograph 12 (*August* 1955).

A discussion of the contemporary status of turbulence measurements utilising the techniques of hot-wire anemometry.—(1.12.6).

*On the theory of shock reflection on walls with slots. W. Eckhaus. N.L.L. Report F.*167 (1955).

The mechanism of shock reflection and cancellation on walls with either transversal or longitudinal slots is studied. Conditions are derived which ensure complete cancellation of the reflected disturbances at an infinitely large distance from the wall.—(1.12.1.2).

Heat loss from yawed hot wires at subsonic Mach numbers. V. A. Sandborn and J. C. Laurence. N.A.C.A. T.N. 3563 (*September* 1955).

Heat-loss data at angles of yaw and fixed subsonic Mach numbers for several wires of different diameters commonly used in hot-wire anemometry are presented. Possible methods of correlating the data are examined. An empirical relation based on weighted addition of the heat losses of wires normal and parallel to the flow correlated all data reasonably well.—(1.12.6.3).

Averaging of periodic pressure pulsations by a total-pressure probe. R. C. Johnson. N.A.C.A. T.N. 3568 (*October* 1955).

Information is presented on the average pressure indicated by a total-pressure probe subjected to a stagnation pressure that alternates periodically between two constant values. Calculated and experimental data are in good agreement, and errors are reduced when the probe design is such as to ensure laminar-flow pulsations in the probe at all times.—(1.12).

FUELS AND LUBRICANTS

An automatic viscometer for non-Newtonian materials. R. N. Weltmann and P. W. Kuhns. N.A.C.A. T.N. 3510 (*August* 1955).

A concentric-cylinder rotational viscometer is described that can measure viscosities from 0·05 to 20,000 poises, programme and record flow curves of rate of shear against shearing stress for most non-Newtonian materials, record time-torque curves, and can produce dynamic flow measurements.—(14.0).

Chemical action of halogenated agents in fire extinguishing. F. E. Belles. N.A.C.A. T.N. 3565 (*September* 1955).

The action of halogenated fire fighting agents is discussed in terms of chain-breaking reactions between agent and active particles (atoms and free radicals). A method for the estimation of rate constants for the reaction of agent with active particles is described, and the rate constant for methyl bromide is obtained.—(14.0).

HYDRODYNAMICS

Investigation of high length/beam ratio seaplane hulls with high beam loadings. Hydrodynamic stability Part I. Techniques and presentation of results of model tests. D. M. Ridland et al. A.R.C. C.P. 201 (*September* 1953).

A background, to be read in conjunction with the individual model test reports, is provided to the hydrodynamic stability side of a research programme on seaplanes with high length/beam ratio hulls and high beam loadings. Methods of testing and presenting results, which it is intended will be used throughout the programme, are described and points requiring further investigation are noted.—(17.2).

Investigation of high length/beam ratio seaplane hulls with high beam loadings. Hydrodynamic Stability Part II. The effect of changes in the mass, moment of inertia and radius of gyration on longitudinal stability limits. J. K. Friswell et al. A.R.C. C.P. 202 (1955).

Tests have been performed to ascertain the effects of varying load, moment of inertia, and radius of gyration on the stability limits of a high length-to-beam-ratio dynamic model. The tests were carried out at high beam loadings, with $C_{\Delta 0}$ in the range 2·00 - 3·00. A theoretical analysis has been made of the relation between the effects of the various parameters, and the results of the analysis compared with experimental results. The effect on the limits of a change from a velocity to a draught base has also been considered.—(17.2).

Investigation of high length/beam ratio seaplane hulls with high beam loadings. Hydrodynamic stability Part X. The effect of afterbody length on stability and spray characteristics. D. M. Ridland. A.R.C. C.P. 203 (*August* 1954, *published* 1955).

The effects of afterbody length on longitudinal stability, spray, directional stability and elevator effectiveness are deduced from the results of tests on four models of the series which were alike in every major respect except that of afterbody length. The models had afterbody lengths of 4, 5, 7 and 9 beams respectively.—(17.2).

Investigation of high length/beam ratio seaplane hulls with high beam loadings. Hydrodynamic stability Part VI. The effect of forebody warp on stability and spray characteristics. D. M. Ridland. A.R.C. C.P. 204 (1955).

The effects of forebody warp on longitudinal stability, spray, directional stability and elevator effectiveness are deduced from the results of tests on three models of length/beam ratio 11, which were alike in every respect except that of forebody warp, the deadrise angle being increased at the rate of 0°, 4° and 8° beam, respectively.—(17.2).

Full scale measurements of impact loads on a large flying boat (Sunderland Mk. 5). Part II—Results from impacts on main step. J. A. Hamilton. A.R.C. C.P. No. 205 (*February* 1951. *published* 1955).

Full scale measurements of landing impact forces and pressures have been made on the hull of a Sunderland Mk. 5 flying boat (weight 50,000 lb.) to provide basic information on the agreement between experiment and the latest available impact theories. The experiments were arranged to give impact conditions as near as possible to those assumed in theory.—(17.2).

Hydrodynamic pressure distributions obtained during a planing investigation of five related prismatic surfaces. W. J. Kapryan and G. M. Boyd, Jr. N.A.C.A. T.N. 3477.

Hydrodynamic pressure distributions have been obtained during pure planing for five related prismatic surfaces. Comparison of experiment with theory shows that existing theories will adequately predict flat-plate pressures. For the V-shaped surfaces, experiment and theory are in poor agreement. The lift and centre-of-pressure data for both the flat and V-shaped surfaces are in good agreement with recent experimental and theoretical N.A.C.A. research on planing surfaces.—(17.2).

MATERIALS

Structural changes during rotating cantilever fatigue tests on annealed copper. R. B. Davies and J. Y. Mann. A.R.L. Report Met. 10 (*November* 1954).

Studies have been made of the structural changes occurring during rotating cantilever fatigue tests on annealed copper at 6,000 c.p.m., using metallograph and X-ray diffraction techniques.—(21.2.2).

Axial-load fatigue properties of 24S-T and 75S-T aluminum alloy as determined in several laboratories. H. J. Grover et al. N.A.C.A. Report 1190 (1954).

In the initial phase of an N.A.C.A. programme on fatigue research, axial-load tests on 24S-T3 and 75S-T6 aluminium-alloy sheet have been made at the Battelle Memorial Institute and at the Langley Aeronautical Laboratory of the N.A.C.A. The test specimens were polished and unnotched. The manufacturer of the material, the Aluminum Company of America, has made axial-load tests on 24S-T4 and 75S-T6 rod material. The test techniques used at the three laboratories are described in detail; the test results are compared with each other and with results obtained on unpolished sheet by the National Bureau of Standards. (This report was formerly T.N.2928).—(21.2.2).

Theory of dynamic creep. A. A. Predvoditelev and B. A. Smirnov. N.A.C.A. T.M. 1330 (*September* 1955).

An analysis is given of the causes of the increase in creep under varying loads. It is suggested that the increase in creep is due to local rise in temperature over the slip planes, thus facilitating slip. A theory of dynamic creep is proposed, based on the Becker theory of the after-effect, which treats the metal as a granular structure and includes a rate factor.—(21.2.0).

MATHEMATICS

A nine's complement decade counter and recorder. J. A. Phillips. A.R.L. Instruments Note 55 (*April* 1955).

A brief outline of decimal counting using weighted binary digits is given with special reference to systems giving complements of nine. A binary decade electronic counter arranged so as to allow the reading of nine's complements, which may be used to represent negative numbers is then described.—(22.1).

From linear mechanics to non-linear mechanics. J. Loeb. N.A.C.A. T.M. 1396 (*February* 1950, *published* 1955).

Consideration is first given to the technique used in telecommunication where a non-linear system (the modulator) results in a linear transposition of a signal. It is then shown that a similar method permits linearisation of electro-mechanical devices or non-linear mechanical devices. A sweep function plays the same rôle as the carrier wave in radio-electricity. The linearisations of certain non-linear functionals are presented.—(22.3).

MECHANICAL ENGINEERING

Experimental investigation of eccentricity ratio, friction, and oil flow of long and short journal bearings with load-number charts. G. B. DuBois et al. N.A.C.A. T.N. 3491 (*September* 1955).

The performance of plain bearings under steady central loading is compared and summarised by single-line curves covering the range of length-diameter ratios both above and below 1. Experimental data on eccentricity ratio, friction, and oil flow for length-diameter ratios of 1, 1-1/2, and 2 are shown for comparison with earlier data for length-diameter ratios of 1/4, 1/2, and 1. The combined data provide charts of plain-bearing performance which cover the practical range of length-diameter ratio.—(23.2.1).

METEOROLOGY

An airborne silver iodide dispensing burner. D. R. Warren and M. V. Nesbitt. A.R.L. M.E. 200 (*May* 1955).

An analysis has been made of the combustion conditions giving maximum efficiency in the dispensing of silver iodide for rain-making purposes. A burner has been designed which, with its fuel tank and control gear could be attached to commercial aircraft as a self-contained automatically-operated pod. It has been shown that the conventional use of kerosine or petrol to maintain combustion is unnecessary, and that the combustion of an acetone solution of AgI can be arranged to give equal efficiency in the production of active nuclei.—(24).

POWER PLANTS

Progress in development of a rig for testing variable area exhaust nozzles for turbojet engines fitted with afterburners. R. J. T. Bruce and J. C. Vrana. N.A.E. Laboratory Report 135 (*May* 1955).

A test rig, consisting of a preheat combustion chamber and a Derwent N.A.E. type afterburner has been developed for testing variable area exhaust nozzles. Air is supplied by a centrifugal compressor set. The air mass flow available is about 50 lb./sec., and to test at the correct pressure ratios a nozzle that was designed for use on an engine having a larger mass flow, a water-cooled plug has been used to reduce the nozzle exit area.—(27.1).

Criterions for prediction and control of ram-jet flow pulsations. W. H. Sterbentz and J. C. Evvard. N.A.C.A. T.N. 3506 (*August* 1955).

Results of a theoretical and experimental study of ram-jet diffuser flow pulsing, commonly referred to as a "buzz condition," with and without combustion are presented. The theoretical approach to the problem is a simpified treatment of the ram-jet likened to act as a Helmholtz resonator. The theoretical resonance criterions reasonably predicted the occurrence of diffuser-flow pulsations.—(27.4).

PROPELLERS

Theory of the broad-bladed propeller. G. I. Ginzel. A.R.C. C.P. No. 208 (*June* 1952, *published* 1955).

The standard propeller theory is that of the lifting line and therefore strictly valid for narrow blades only. The present first step towards a theory of the propeller blade as a lifting surface considers besides the downwash which induces an inclination of flow, the downwash derivative and the corresponding induced camber of the streamlines in the special case of shock free entry of flow at the leading edge. The result is given in the form of a correction factor to be applied to the camber ratio of the section derived by the lifting line theory.—(29.1).

SCIENCE—GENERAL

Optical characteristics of laminated camera windows. A. C. Marchant and B. M. Mathieson. A.R.C. C.P. No. 210 (*March* 1955).

This Note describes optical tests on laminated camera windows of both plane and spherical form. Photographic tests of their effect upon the resolving power of an associated camera system have been made. The wedge angle of the windows has been measured, and the surface flatness and internal homogeneity of the plane windows tested; the effects of the curved windows, upon the correction of the camera lens associated with them, has been assessed visually.—(32.2.4).

STRUCTURES

LOADS

See also: THEORY AND ANALYSIS TESTING

Effect of interaction on landing-gear behavior and dynamic loads in a flexible airplane structure. F. E. Cook and B. Milwitzky. N.A.C.A. T.N. 3467 (*August* 1955).

The effects of interaction between a landing gear and a flexible aeroplane structure on the behaviour of the landing gear and the loads in the structure have been studied by treating the equations of motion of the aeroplane and the landing gear as a coupled system, where the landing gear is considered to have non-linear characteristics. Numerical examples, based on the characteristics of two large aeroplanes, show the effects of interaction on the loads in the landing gear and in the structure.—(33.1.2).

Analysis of acceleration, airspeed, and gust-velocity data from one type of four-engine transport airplane operated over two domestic routes. M. R. Copp and T. L. Coleman. N.A.C.A. T.N. 3475 (*October* 1955).

Time-history data obtained by the N.A.C.A. V.G.H. recorder from one type of four-engined commercial transport aeroplane during operations on two domestic routes indicated that the number of gust accelerations experienced per mile of flight by the two operations differed by a factor of roughly 3. The number of gusts per mile of flight differed by a factor of roughly 4.—(33.1.1).

Analysis of the horizontal-tail loads measured in flight on a multi engine jet bomber. W. S. Aiken, Jr. and B. Wiener. N.A.C.A. T.N. 3479 (*September* 1955).

Horizontal-tail loads were measured in gradual and abrupt longitudinal manoeuvres on two configurations of a four-engined jet bomber. The results obtained have been analysed to determine the flight values of the coefficients important in calculations of horizontal-tail loads. The least-squares procedure used to determine aerodynamic tail loads from strain-gauge measurements of structural tail loads which were affected by temperature is covered in detail. The effect of fuselage flexibility on the aeroplane motion is considered in the analysis of the abrupt-manoeuvre data.—(33.1.1).

Analysis of acceleration, airspeed and gust-velocity data from a four-engine transport airplane in operations on an Eastern United States route. T. L. Coleman and M. W. Fetner. N.A.C.A. T.N. 3483 (*September* 1955).

Time-history data obtained by the N.A.C.A. V.G.H. recorder from one model of a four-engined civil transport aeroplane during operations on an eastern United States route are analysed to determine the magnitude and frequency of occurrence of gusts, gust accelerations, and the associated air speeds. Comparison of the results with previously reported results indicates the gust-load history to be more severe than for two other similar operations involving other types of four-engined transports.—(33.1.1).

Summary of derived gust velocities obtained from measurements within thunderstorms. H. B. Tolefson. N.A.C.A. T.N. 3538 (*October* 1955).

Available measurements of the derived gust velocities within thunderstorms are summarised for altitudes from 5,000 to 34,000 ft. The results indicate that the intensity of the derived gust velocity is essentially constant up to altitudes of 20,000 ft. and that an approximate 10 per cent. reduction in the gust intensity occurs for altitudes from 20,000 to 30,000 ft.—(33.1.1).

Reevaluation of gust-load statistics for applications in spectral calculations. H. Press and M. T. Meadows. N.A.C.A. T.N. 3540 (*August* 1955).

The available information on the spectrum of atmospheric turbulence is briefly reviewed. On the basis of these results, a method is developed for the conversion of available gust statistics normally given in terms of counts of gust peaks into a form appropriate for use in spectral calculation. The fundamental quantity for this purpose appears to be the probability distribution of the root-mean-square gust velocity. Estimates of the variation of this distribution with altitude and weather condition are also derived from available gust statistics.—(33.1.1).

THEORY AND ANALYSIS

Effect of tight clamping on the fatigue strength of joints. W. A. P. Fisher and W. J. Winkworth. R. & M. No. 2873 (*February* 1952, *published* 1955).

The effect of clamping on the fatgiue strength of joints in aluminium alloy is investigated experimentally. Tests on Z-section stringers connected to long, slotted cleats give an endurance for tightly clamped joints about nine times that for unclamped joints. Tests of bolted joints in aluminium alloy sheet material show still greater improvement for very tight clamping. In both series of tests, the clamping tends to cancel the weakness in fatigue of a loaded hole.—(33.2.4.13.10).

*Shear tests on 24S-T unstiffened and stiffened webs with flanged holes. Part II. M. Botman. N.L.L. Report S.*446.

The results are given of tests on 32 specimens, being an extension of the tests described in Report No. S413. The same test methods were employed. The buckling, yield and ultimate allowable stresses are presented in the form of non-dimensional diagrams. The initial effective modulus of rigidity is also determined.—(33.2.4.6.4).

Effective width in the plastic range of flat plates under compression (Part III). M. Botman. N.L.L. Report S. 465 (1955).

This is an extension of the tests described in N.L.L. Report 5445. The same methods were employed. Results are given of tests on 18 plates, 10 of which are made of aluminium alloy 75S-T and 8 of aluminium alloy 2S-½H.—(33.2.2 × 33.2.4.5.1).

Investigation of the vibrations of a hollow thin-walled rectangular beam. E. E. Kordes and E. T. Kruszewski. N.A.C.A. T.N. 3463 (*October* 1955).

Experimental modes and frequencies of an unstiffened hollow beam of rectangular cross section are presented, and comparisons are made between experimental and theoretical frequencies. Theories based on rigid cross sections were found to be sufficiently accurate to predict the frequencies of only the lowest three bending modes. For the higher bending modes and all the torsional modes, it was necessary to include the effects of cross-sectional distortions in the calculations.—(33.2.4.1.10 × 33.1.2).

Influence of shear deformation of the cross section on torsional frequencies of box beams. E. T. Kruszewski and W. W. Davenport. N.A.C.A. T.N. 3464 (*October* 1955).

An exact analysis has been made on the torsional vibrations of a four-flange box beam with cross sections which can change shape because the stiffness of the bulkheads is finite. The effect of shear deformation of the cross section on the torsional frequencies is illustrated by numerical calculations. An approximate method for estimating quickly the effects of bulkhead shear stiffness on the torsional frequencies of box beams has been devised.—(33.2.4.1.10 × 33.1.2).

Rapid radiant-heating tests of multiweb beams. J. N. Kotanchik et al. N.A.C.A. T.N. 3474 (*September* 1955).

Results are described of rapid-heating tests on four unloaded multiweb box beams. Temperature distributions and strains measured during a heating cycle are given. An analysis of the thermal stress required to cause buckling is in agreement with the experimentally observed results. A transient heating apparatus used in the tests and capable of producing heating rates up to 100 B.th.u./ft.²-sec. is described.—(33.2.4.1.9).

Development of equipment and of experimental techniques for column creep tests. S. A. Patel et al. N.A.C.A. T.N. 3493 (*September* 1955).

Equipment and procedures developed for testing aluminium alloy columns subjected to constant loads at elevated temperatures are described. Particular emphasis was put on determination of the influence of initial deviations from straightness on the critical time of the column, that is, the time necessary for the column to buckle when subjected to a constant load. Results are presented of tests of a number of 2024-T4 aluminium-alloy columns having large slenderness ratios.—(33.2.4.2.6).

TESTING

Calibration of strain-gage installations in aircraft structures for the measurement of flight loads. T. H. Skopinski et al. N.A.C.A. Report 1178 (1954).

A general procedure is developed for calibrating strain-gauge installations in aircraft structures for application to flight measurements of loads. The basic procedure can be modified as necessary to suit the requirements of any particular structure. The application of the procedure is illustrated by results for two typical structures. (This Report was formerly T.N.2993).—(33.3.1 × 33.1.1).

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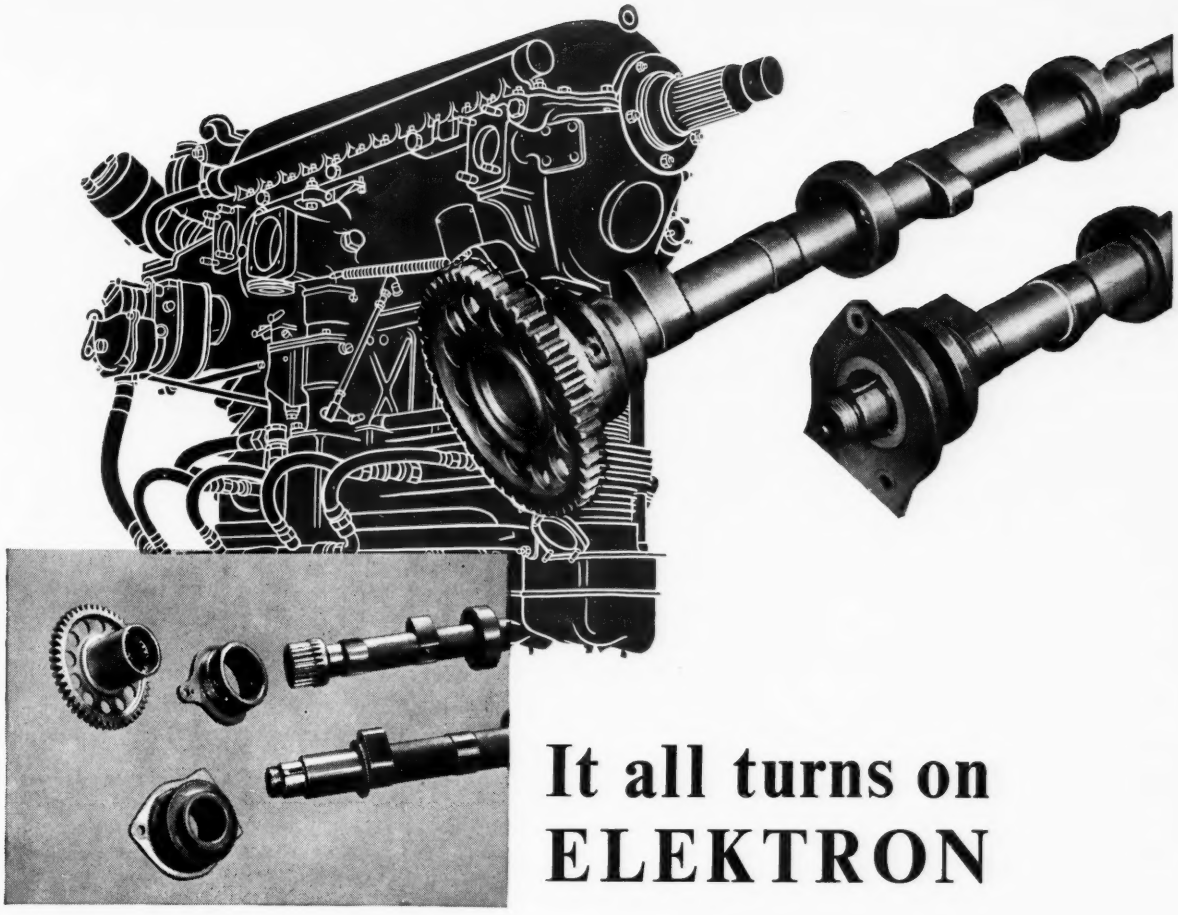

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